University of Alberta

Sedimentology and Depositional Architecture of the Cayman (Miocene) and Pedro Castle (Pliocene) Formations on Western Grand Cayman, British West Indies

by

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A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Master of Science

Department Earth and Atmospheric Sciences

Edmonton, Alberta
Fall 2004

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ISBN: 0-612-95741-1
Our file Notre référence
ISBN: 0-612-95741-1

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Acknowledgments

Thanks to the carbonate group for their friendship and help over the years (Alex MacNeil, Morag Coyne, Lisa Mackinnon, Jen Beanish, Rong-Yu Li, Sandy Bonny, and Dustin Rainey). Thanks to Brian Jones, my supervisor, for his guidance and fine tooth comb editing. Thank you to my family for their support and not bugging me too much to get finished. And finally, a massive thanks to my boyfriend (now husband) David Mills for his long suffering love, support, and computer skills.

I'd also like to thank Grand Cayman's Department of Envionments, the Water Authority, and all the hard working folks who drilled and prepared the core used in this study. That includes Ian Huner, Kenton Phismeter, Bill Kalbfleisch, Jennifer Vezina, Jason Montpetit, and Anurag Shourie. This research was funded by a grant from the Natural Science and Engineering Research Council of Canada A6090 to Brian Jones.

Table of Contents

Chapter 1: Introduction.....1

General Information.....1

Study Objectives.....3

Relevance of These Studies.....3

Location.....5

Tectonic History.....8

Stratigraphy.....9

Methods.....11

Chapter 2: Sedimentology and Facies Architecture of the Cayman Formation.....13

Skeletal Components.....13

Preservation of Skeletal Components.....14

Coralline Algae.....14

Foraminifera.....17

Echinoids.....17

Coral.....17

Green Algae and Molluscs.....18

Facies of the Cayman Formation and their Interpretation.....18

Stylophora Facies Association.....18

Stylophora- Porites Facies.....26

Laminar Coral Facies.....29

Skeletal Facies Association.....30

Porites- Intraclast- Rhodolith Facies.....32

Intraclast Facies.....34

Facies Architecture.....37

Unit I.....37

Unit II.....40

Skeletal Facies Association.....40

Water Depth versus Water Energy.....41

Comparison with other Cayman Formation Studies.....41

Safe Have- western Grand Cayman.....44
Roger's Wreck Point- Eastern Grand Cayman.....46
Tarpon Springs Estates-southern Grand Cayman.....47
Cayman Brac.....48
Summary.....49
Chapter 3: Sedimentology and Facies Architecture of the Pedro Castle Formation 50
Skeletal Components and Preservation.....53
Facies of the Pedro Castle Formation and their Interpretation.....61
Rhodolith- Foraminifera Facies 61
Trachyphyllia- Foraminifera- *Halimeda* Facies.....65
Foraminifera- *Halimeda*- Bivalve Facies..... 67
Foraminifera- Mollusc- *Halimeda* Facies.....68
Foraminifera- *Halimeda*.....70
Stylophora- Amphistegina Facies 70
Facies Architecture.....71
Discussion.....77
Controls on Deposition.....78
Summary.....81
Chapter 4: Depositional Controls on Modern Banks and Characterization of those Controls in the Miocene and Pliocene 82
Miocene and Pliocene Wind and Current Patterns.....85
Climate and Sea level.....88
Miocene and Pliocene coral assemblages.....88
Implications for Deposition of the Cayman and Pedro Castle Formations.....90
Cayman Formation.....90
Pedro Castle Formation.....95
Summary.....98
Conclusions.....99
References.....100
Appendix A- Well Logs..... 107

List of Tables

Table 2.1 Facies of the Cayman Formation.....19,20

Table 3.1 Facies of the Pedro Castle Formation.....62,63

List of Figures

Fig. 1.1 Location Map.....2

Fig. 1.2 Map of Grand Cayman.....4

Fig 1.3 Stratigraphic Column.....6

Fig. 1.4 Regional Tectonic and Stratigraphic Map.....7

Fig 1.5 Major Tectonic Features of the Caribbean Region.....7

Fig 2.1 Core from the *Stylophora* Facies.....15

Fig 2.2 Core from the *Stylophora- Halimeda* Facies.....15

Fig 2.3 Thin section photographs of the Cayman Formation.....16

Fig 2.4 Thin section photographs of the Cayman Formation.....16

Fig 2.5 Thin section photographs of the Cayman Formation.....16

Fig 2.6 Thin section photographs of the Cayman Formation.....16

Fig 2.7 Cayman Formation N-S cross section.....21

Fig 2.8 Biota Distribution with Depth.....25

Fig 2.9 Core from the *Stylophora- Porites* Facies.....27

Fig 2.10 Core from the Laminar Coral Facies.....27

Fig 2.11 Core from the Skeletal Facies Association.....30

Fig 2.12 Core from the Skeletal Facies Association.....30

Fig 2.13 Core from the *Porites*- Intraclast- Rhodolith Facies 33

Fig 2.14 Core from the *Porites*- Intraclast- Rhodolith Facies 33

Fig 2.15 Core from the Intraclast Facies 35

Fig 2.16 Core from the Intraclast Facies 35

Fig 2.17 The Cayman Formation in SH#1, SH#2, SH#3.....36

Fig 2.18a Depositional units of the Cayman Formation.....38

Fig 2.19 Depositional Units in SH#1, SH#2, SH#3.....39

Fig 2.20 The influence of water energy and depth on the Cayman Formation.....42

Fig 2.21 Relative position of Cayman Formation sediments on Grand Cayman and Cayman Brac.....43

Fig 2.22 The Cayman Formation in the Safe Haven area 45

Fig 3.1 The Cayman Unconformity Surface.....51

Fig 3.2 Distribution of the Cayman, Pedro Castle, and Ironshore formations on Grand Cayman's western peninsula.....52
Fig 3.3 Comparison of the characteristics of the Cayman and Pedro Castle formations..54
Fig 3.4 Thin section photographs of the Pedro Castle Formation.....55
Fig 3.5 Thin section photographs of the Pedro Castle Formation.....56
Fig 3.6 Thin section photographs of the Pedro Castle Formation.....57
Fig 3.7 Thin section photographs of the Pedro Castle Formation.....59
Fig 3.8 Core from the Rhodolith-Foraminifera Facies 60
Fig 3.9 Core from the Rhodolith-Foraminifera Facies 60
Fig 3.10 Core from the *Trachyphyllia*- Foraminifera- *Halimeda* Facies.....66
Fig 3.11 Core from the Foraminifera- Mollusc- *Halimeda* Facies 69
Fig 3.12 Core from the *Stylophora- Amphistegina* Facies.....69
Fig 3.13 Distribution of the Pedro Castle Formation Facies.....72
Fig 3.14 Facies Architecture of the Pedro Castle Formation Facies.....73
Fig 3.15 Distribution of the Pedro Castle Formation Facies in SH#1, SH#2, SH#3.....74
Fig 3.16 Facies Architecture for SH#1, SH#2, SH#3.....76
Fig 3.17 The influence of water energy and depth on the Pedro Castle Formation.....79
Fig 3.18 Sediment Distribution Due to Gradual and Sharp Sea Level Increases.....80
Fig 4.1 The Influence of Storms, Winds, and Currents on Modern Grand Cayman.....84
Fig 4.2 Timeline of Events Affecting Currents in the Caribbean Region.....86
Fig 4.3 Evolution of Cenozoic Paleocurrent Patterns for the Caribbean Region.....87
Fig 4.4 Third Order Sea Level Curves for the Miocene and Pliocene.....89
Fig 4.5 Montpetit's (1998) Relative Sea Level Curve for the Cayman Formation at Tarpon Springs Estates.....94
Fig 4.6 Third Order Sea Level Curve for the Pliocene.....96

Chapter 1: Introduction

General Information

Grand Cayman is an isolated carbonate platform located in the north central Caribbean (Figure 1.1). It is a low-lying, tropical island with limited outcrop exposures. The island is partially capped by Pleistocene carbonates; Tertiary carbonates crop out in the east and south-central regions of the island (Figure 1.2). Shallow water carbonates of the Bluff Group make up the core of the island (Figure 1.3. These include the Lower Oligocene Brac Formation, the Middle to Upper Miocene Cayman Formation and the Pliocene Pedro Castle Formation (Jones et al., 1994b). Unconformities bound all four formations. The Cayman Formation is entirely dolostone, the Brac and Pedro Castle formations are partially dolomitized, and the Ironshore Formation is limestone (Jones et al, 1994b).

Grand Cayman provides an extensive record of Tertiary and Quaternary shallow water carbonate deposition, from which depositional conditions can be interpreted. The isolated setting of Grand Cayman, as well as the relative youth of the strata, also facilitates diagenetic studies. These factors have prompted study of Grand Cayman by researchers such as Matley (1926), Brunt et al. (1973), Rigby and Roberts (1976), Woodroffe (1988), Woodroffe et al. (1980, 1983), Machel (2000), and Jones et al. (multiple publications). Surface studies of the island, however, are restricted by the limited relief of the island, flat- lying strata, surface karst, and coverage by Pleistocene limestones and extensive tropical overgrowth (Wilson, 1998).

In 1994, core became available for subsurface study, through a drilling program initiated by Brian Jones of the University of Alberta. Subsurface studies have since been completed on the Cayman Formation and Pedro Castle Formation at various localities on Grand Cayman by Wignall (1995), Wilson (1998), Montpetit (1998), and Arts (2000). This study builds on these previous works, applying their findings to a north south transect (Figure 1.2) that extends over most of Grand Cayman's western peninsula. Seven cores have been used in this study, six of which were either not studied, or only had the Pedro Castle Formation previously examined. The seventh core, SH#3, was used as a reference section by Jones et al. (1994) for the Pedro Castle Formation. This core was

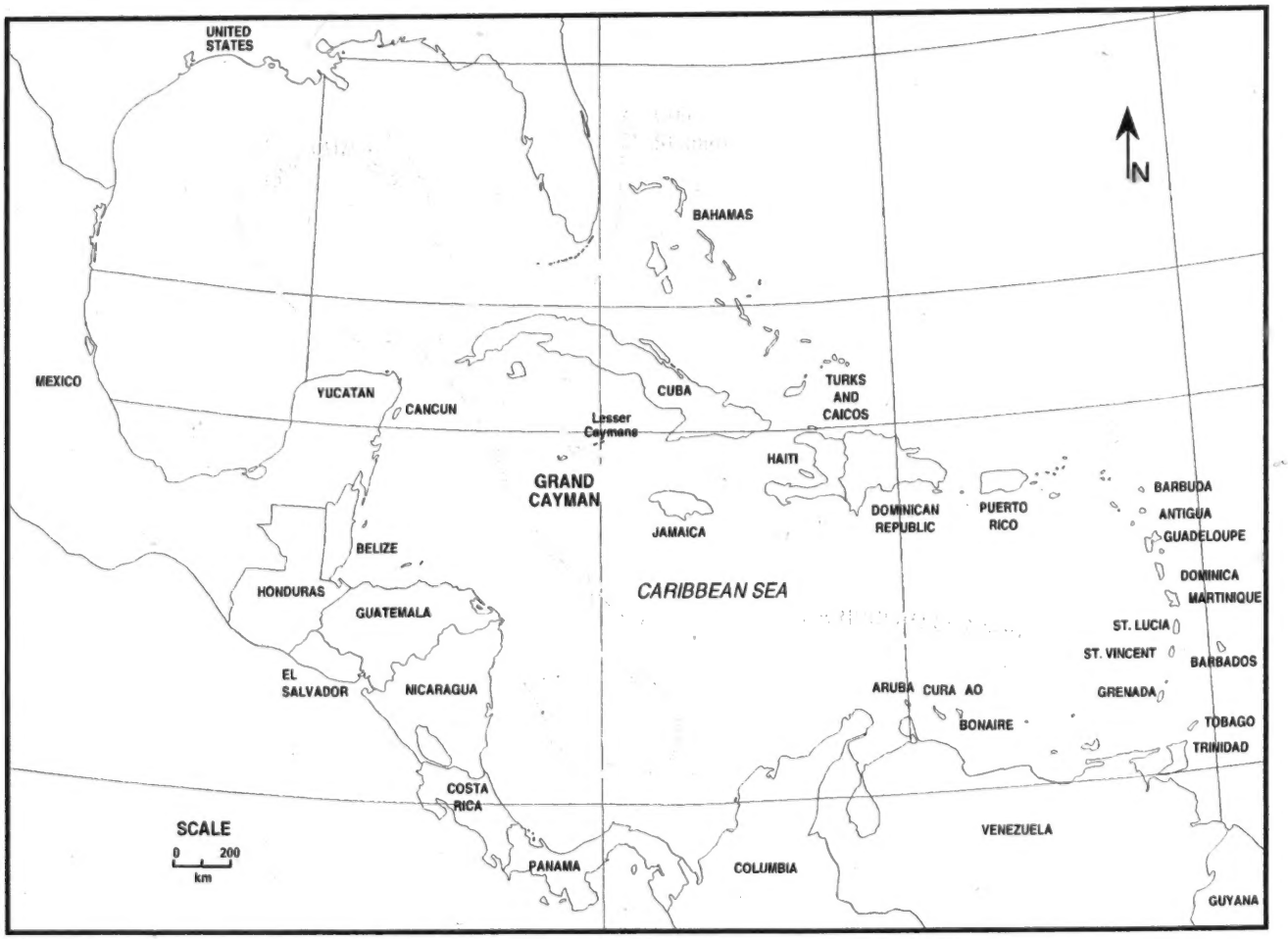


Figure 1.1. Location map. Grand Cayman is located north of center in the Caribbean Sea. It is the largest, and western most of the three Cayman Islands. Modern oceanic current patterns are shown in gray (modified from Blanchon, 1995).

also part of Brent Wignall's (1995) study of the Cayman Formation and Pedro Castle Formation at Safe Haven, (Figure 1.2). This core was used as a calibration core for the current study.

Study Objectives

The objectives of this study are:

1. To determine the of depositional environments represented in the upper part of the Cayman Formation and Pedro Castle Formation along a north to south transect located on the western peninsula of Grand Cayman (Figure 1.2).
2. To integrate the results of this study with those obtained by Wignall (1995) and Arts (2000) who examined equivalent strata on different parts of the island.
3. To determine the changes in sea level during the time period represented by the upper part of the Cayman Formation and the Pedro Castle Formation.
4. To document the pattern of dolomitization in the Pedro Castle Formation of the study area.

Relevance of these studies:

The Upper Miocene and Pliocene were periods of dramatic fluctuation in sea level. Changes in ocean circulation patterns in the Cenozoic led to advancing and retreating antarctic glaciation that produced sea level changes of possibly more than 100 m in as short as a million years (Vail and Hardenbol, 1979). Global sea level curves have been compiled by Vail and Hardenbol (1979), Hallam (1984), and Haq et al (1987) but differ in terms of timing and magnitude of highstands. Haq et al.'s (1987) sea level curve shows a rise in sea level in early Pliocene and a regression in the late Pliocene. This is in contrast to Hallam's (1984) sea level curve, which shows a lowstand in the early Pliocene, followed by a highstand in the late Pliocene. Determination of depositional environments of the Cayman Formation and the Pedro Castle Formation on Grand Cayman's western peninsula will provide a local record of relative sea level changes. This will contribute to global knowledge of sea level changes in the Miocene and Pliocene. Better sea level curves can more accurately bracket depositional timing. More

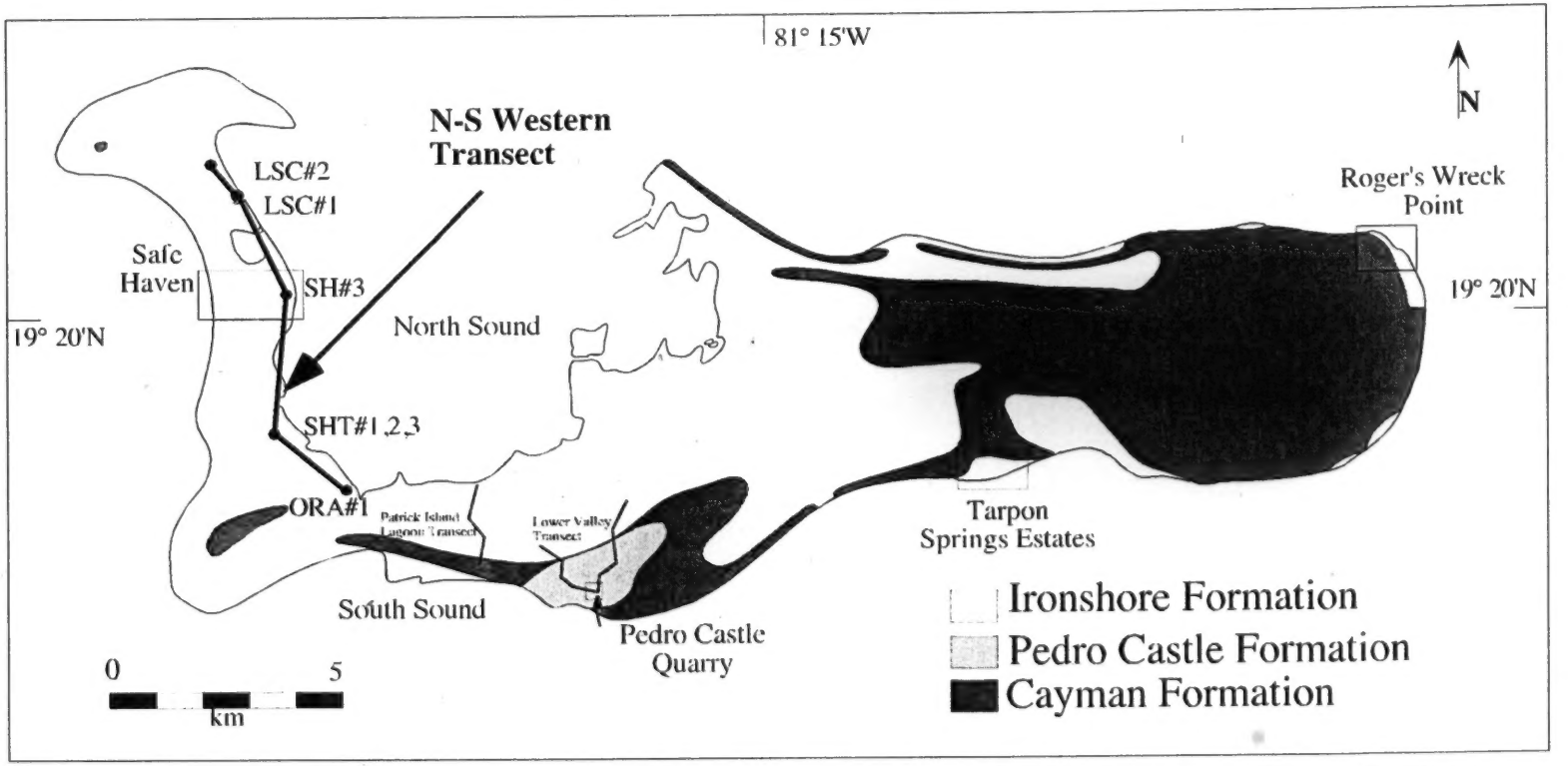


Figure 1.2. Detailed Grand Cayman location map showing surface cover by the Ironshore, Pedro Castle, and Cayman Formations. The N-S transect along the western peninsula is the focus of this study (modified from Arts, 2000).

accurate associations can also be made between sea level and circulation changes, climatic patterns, faunal turnovers, and other phenomena.

The relative youth and isolated setting of Grand Cayman facilitates dolomitization studies. Possible fluid chemistries, fluid flow mechanisms, and thermodynamic conditions are all constrained by these factors. The young age of the island precludes extensive overprinting and increases the accuracy of event dating. A mixing zone induced by seawater circulation was proposed as the fluid flow mechanism responsible for dolomitization on Grand Cayman by Ng (1990). The dolomitizing fluid was thought by Pleydell, (1987), Pleydell et al. (1990), and Montpetit (1998) to be normal seawater, and by Ng (1990) to be slightly brackish. The number of phases of dolomitization is more controversial as both single (Pleydell, 1987; Jones and Hunter, 1989; Pleydell et al., 1990) and multiple (Ng, 1990; Wignall, 1995; Montpetit, 1998) phases have been proposed. Documentation of the pattern of dolomitization along the western transect will contribute to the overall understanding of the dolomitization process on Grand Cayman.

Location

Grand Cayman is the largest of the three Cayman Islands: Grand Cayman, Cayman Brac, and Little Cayman (Figure 1.1). Grand Cayman is 35 km long and up to 14 km wide, with an areal extent of 197 km^2. Grand Cayman is situated 130 km to the west of the two Lesser Caymans and is located approximately 240 km south of Cuba and 280 km northwest of Jamaica. Grand Cayman is located between latitudes 75^0 44'W and $81^0$27'W, longitude $19^0$15'N and $19^0$45'N. The Cayman Islands are located on separate fault blocks (Woodroffe, 1988).

The Cayman Islands are prominences on the submerged Cayman Ridge (Figure 1.4). The Cayman Ridge extends across the northwest Caribbean from Belize to the Oriente Province, Cuba (Holcombe et al. 1990). To the northwest of the Cayman Ridge is the Yucatan Basin, with water depths up to 4,500 m. To the south of the Cayman Ridge is the Cayman Trough (originally termed the Bartlett Deep), a 100-150 km wide, 1,400 km long extensional zone that reaches depths in excess of 7000 m (Pindell and Barrett, 1990; Beanish, 2000). The Cayman Trough marks the present position of the northern Caribbean strike-slip plate boundary, which is defined by the Oriente transform fault to

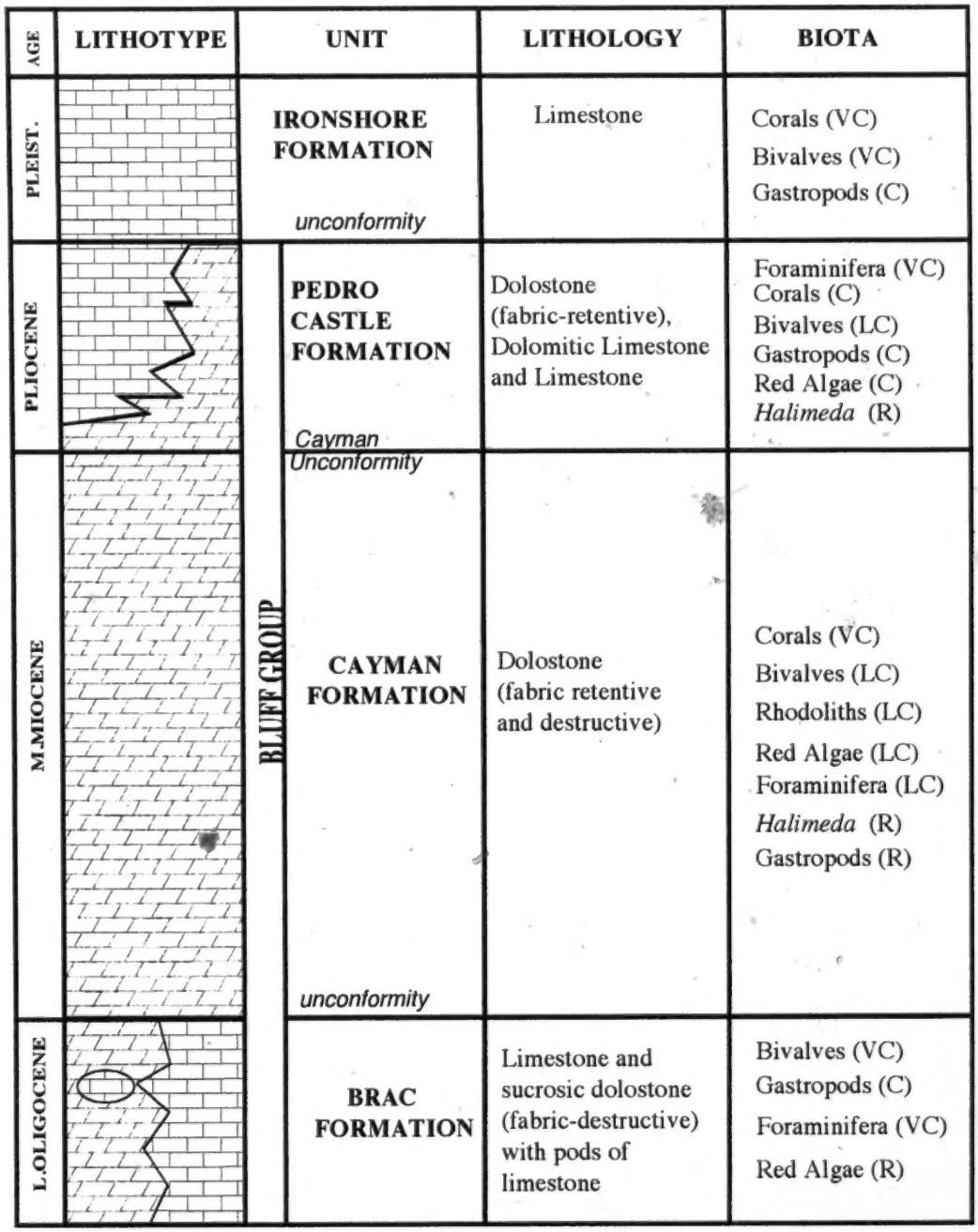


Figure 1.3. Stratigraphic column for the Cayman Islands (after Jones, 1994).

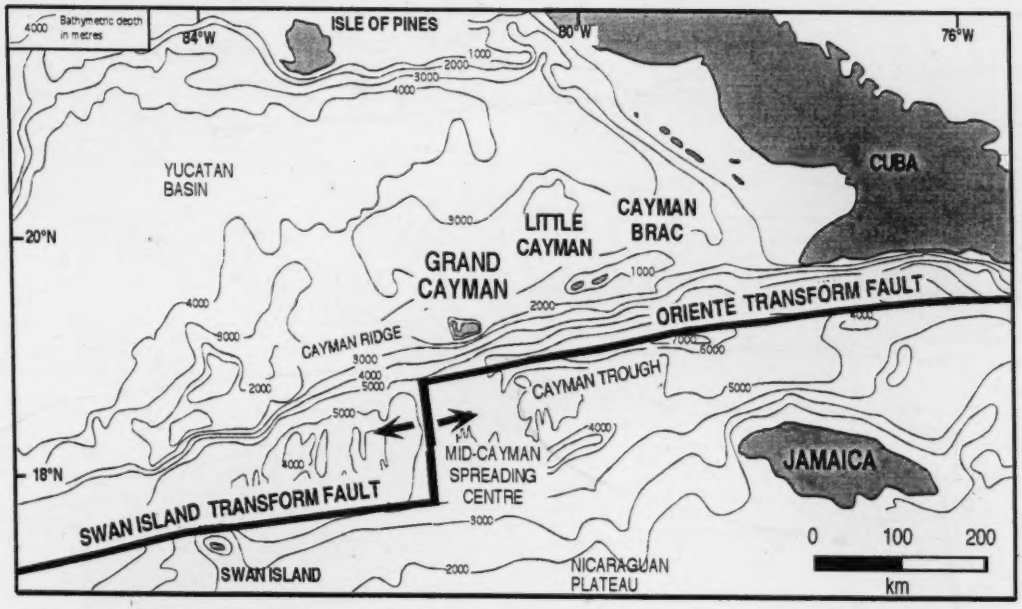


Figure 1.4. Regional tectonic and bathymetric map of the northern Caribbean (modified from Pleydell et al., 1990). Map area corresponds roughly to the boxed area in Figure 1.5.

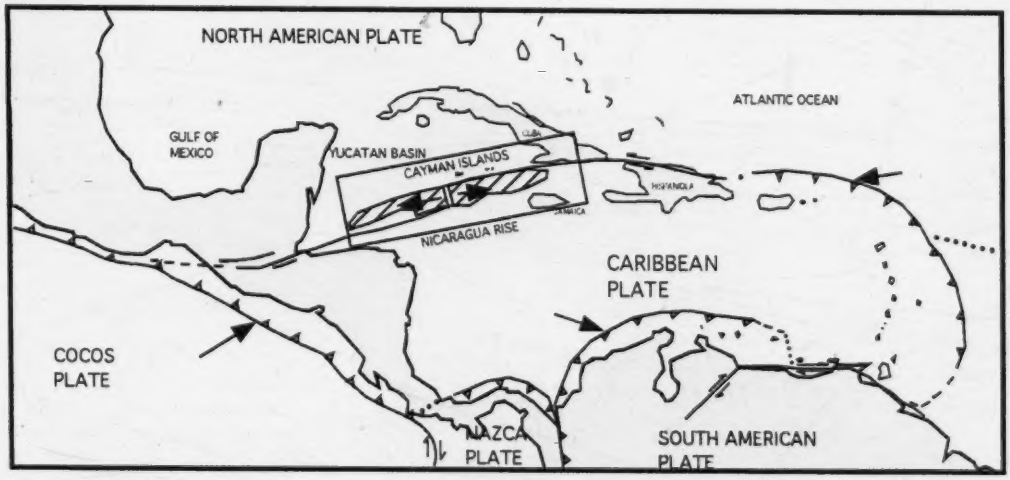


Figure 1.5. Major tectonic features of the Caribbean region. Boxed area outlines the Cayman Trough (Modified from Rosencrantz et al., 1988).

the northwest and the Swan transform fault to the southeast (Rosencrantz et al., 1988; Ladd et al, 1990). The two transform faults are connected at $81^{0}40'$W by the Mid-Cayman Spreading Centre, which is still active today. The Nicaraguan Plateau borders the Cayman Trough to the south.

Tectonic History

The present-day Caribbean plate boundary configuration was established by the late Pliocene (Figure 1.5) (Sykes et al., 1982; Mann et al., 1990; Pindell and Barrett, 1990). The Caribbean Plate can be regarded as a buffer plate whose movements are now governed by the motions of the larger North and South American Plates (Sykes et al., 1982). The Caribbean Plate is allochthonous with respect to the neighboring American plates, and is made up of a collection of allochthonous terranes whose exact relative motions are poorly known (Pindell and Barrett, 1990). The geologic evolution of the Caribbean region is complex, with multiple proposed evolutionary models, and often conflicting interpretations regarding geologic phenomena (Case et al., 1990; Morris et al., 1990; Pindell and Barrett, 1990). The tectonic history of the Cayman Ridge has been extrapolated back to the Mesozoic at which time the ancestral Cayman Ridge and the Nicaraguan Plateau are thought to have been a single unit located on the Caribbean Plate (Perfit and Heezen, 1978). In the Early Cretaceous plate tectonic movements led to the subduction of Atlantic oceanic lithosphere beneath the Caribbean Plate, causing the formation of a broad emergent volcanic arc (Perfit and Heezen, 1978; Holcombe et al., 1990; Pindell and Barrett, 1990). This volcanic arc included the Cayman Ridge as well as the Nicaraguan Plateau, Hipaniola, Jamaica, Puerto Pico, the Virgin Islands, and parts of Cuba (Sykes et al., 1982; Pindell and Barrett, 1990). In the Early Tertiary this island arc was rifted apart due to left lateral shear and tensional stresses along the plate boundary, separating the Cayman Ridge from the Nicaraguan Plateau (Perfit and Heezen, 1978), and transferring the Cayman Ridge to the southern boundary of the North American Plate. This movement led to the opening of the Mid-Cayman Spreading Centre in the Late Paleocene and Early Eocene (Holcombe et al., 1990). Since that time a sinistral offset of up to 1,100 km has separated the Caribbean and the North American plates (Pindell and Barrett, 1990). This timing agrees with spreading rates on the order of

20 mm/yr for the Mid-Cayman Spreading Centre, although there is no agreement on the exact rate of spreading (Ladd et al., 1990; Pindell and Barrett, 1990).

A dredging program undertaken by Perfit and Heezen (1978) along the Cayman Ridge (but to the west of Grand Cayman) recovered island-arc type plutonics and volcanics with genetically associated clastics and carbonates of Cretaceous age that provide support for an island arc origin for the Cayman Ridge. Carbonate rocks were found above this, becoming dominant above 2,500 m bsl in the western portion of the sampled Cayman Ridge and above 1,000 m bsl in the eastern portion. Most of the older recovered carbonates (lower Cretaceous to Oligocene/Miocene) are biomicrites characteristic of neritic carbonate bank or shelf environments (Holcombe et al., 1990). Miocene to Pleistocene carbonates are generally micritic oozes characteristic of a deeper pelagic environment. The banks and shallow crests of the Cayman Ridge (Cayman Islands, Rosario Bank, Misteriosa Bank) are an exception to this, as their Miocene to Recent deposits are characterized by shallow water carbonates.

The dredged material indicates that uplift and erosion took place along the arc before the Eocene. By middle Eocene activity had ceased along the arc and general submergence took place (Holcombe et al., 1990). Perfit and Heezen (1978) estimated a general post- Eocene subsidence rate of 6 cm/1000 yr along the northern Caribbean margin. This is higher than Emery and Milliman's (1980) estimate of a 0.1-1.3 cm/1000 yr subsidence rate for the core of Grand Cayman. Perfit and Heezen (1978), however, described localized uplift as having elevated the Cayman Islands (as well as Central America, the Swan Islands, Jamaica, and most of southern Cuba) since the middle Miocene. The Cayman Islands are located on separate fault blocks, and have been subject to independent vertical tectonic movement since the Miocene, although they appear to have been stable since at least the last interglacial (Woodroffe, 1988).

Stratigraphy

The first detailed geological maps and rock descriptions of the Cayman Islands were published by Matley in 1926. These publications were based on 11 days of fieldwork in 1924, and four brief reports by him in 1924 and 1925. Matley (1926) designated the hard, white, crystalline carbonate that made up the core of the Cayman

Islands (and formed steep cliffs on the topographically higher Cayman Brac) the Bluff Limestone, and assigned an Oligocene to Miocene age to the strata. He named the Pleistocene limestone that fringed all three islands the Ironshore Formation.

This work remained essentially unrevised until Jones and Hunter (1989) recognized the Cayman and Pedro Castle members in the Bluff Limestone. They also suggested that the Bluff Limestone be called the Bluff Formation, due the fact that the Bluff Limestone was mostly dolostone (Jones 1994; Pleydell, 1987; Pleydell and Jones 1988; Jones and Hunter, 1989). Jones et al (1994a, 1994b) further revised the stratigraphic nomenclature of the Tertiary strata by elevating the Bluff Formation to Group status, the Cayman and Pedro Castle members to formational status, and designating the Brac Formation as the oldest formation in the Bluff Group (Figure 1.3).

The Brac Formation is described from Cayman Brac outcrops (Jones et al., 1994a); and has only recently been found in the Grand Cayman subsurface. Foraminifera biostratigraphy and $^{87}Sr/^{86}Sr$ isotope ratios indicate deposition during the late Early Oligocene. Lithology varies from limestone with minor amounts of dolomite to fabric destructive sucrosic dolostone with isolated pods of partly replaced limestone. *Lepidoclyclina* (foraminifera) wackestones and packstones dominate the sediments, mollusk dominated sediments also occur. The depositional environment is thought to have been a very shallow water bank, less than 10 m deep, possibly associated with sea grasses (Hunter, 1994; Jones and Hunter, 1994). The lower boundary of the Brac Formation has not been found. The upper boundary is a disconformity that developed during the Middle Oligocene (Arts, 2000), and may represent 15 million years (Jones and Hunter, 1994b). Topographic relief of the Brac Formation Cayman Brac is at least 25 m.

The Cayman Formation is estimated to be middle Miocene in age (Jones, 1994). This is based on fauna and stratigraphic setting, although a lack of age diagnostic fossils and $^{87}Sr/^{86}Sr$ signatures reset during dolomitization makes this uncertain (Jones et al., 1994). The lithology is fabric retentive microcrystalline dolostone. The Cayman Formation has a more diverse biota assemblage than the Brac Formation, especially in terms of coral species (Hunter, 1994). Deposition is thought to have taken place in shallow (less than 30 m deep), warm water with good cross-bank circulation (Hunter, 1994).

The upper boundary of the Cayman Formation is the Cayman Unconformity. This unconformity represents a sea level drop of at least 41 m below present day sea level, and was developed over a period of possibly 1.5 million years during the terminal Miocene (Messinian) low stand (Jones and Hunter, 1994a). Karsting associated with the lowstand produced a topographical low over the western end of Grand Cayman. Dolomitization of the Cayman Formation has also been associated with this event (Wignall, 1995).

$^{87}Sr/^{86}Sr$ isotope ratios and fauna indicate a Pliocene age for the Pedro Castle Formation. The lithology is a mixture of fabric retentive dolostone, dolomitic limestone, and limestone. Dominant biota includes corals, foraminifera, and green algae. The Pedro Castle Formation sediments have been recorded as being less coarse than the Cayman Formation sediments, and are thought to have been deposited in lower energy, shallower water conditions (Hunter, 1994). Termination of sedimentation of the Pedro Castle Formation corresponds to the onset of Pleistocene glaciation in the Northern Hemisphere (Arts, 2000). The unconformity surface is karsted and uneven.

The Ironshore Formation is Pleistocene in age and unconformably overlies the Bluff Group. The Ironshore Formation is limestone, and is typically formed of friable, poorly consolidated reefal limestones, calcarenites, and calcite cemented oolitic limestones (Vézina, 1997; Coyne, 2003).

The attitude of the strata on Grand Cayman appears to be horizontal, exposing limited strata of the Ironshore, Pedro Castle, and Cayman formations (Jones and Hunter, 1994a). No outcrops of the Brac Formation occur on Grand Cayman, however, the Brac Formation is exposed as high as 33 m asl on the nearby Cayman Brac, due to a 0.5^0 dip of the strata to the west (Jones and Hunter, 1994a).

Methods

Cores from 7 wells along a north to south transect on the northern peninsula of Grand Cayman were examined. Detailed log and thin section descriptions were used to define facies and interpret depositional environments. The facies architecture of the north to south transect was constructed and integrated with Wignall's (1995) east to west transect over the centre of the western peninsula, and Arts (2000) facies work on the

Pedro Castle Formation of the western peninsula. Changes in depositional conditions over space and time were then interpreted for the western peninsula of Grand Cayman.

Dolomite content was quantified for thin sections from the Pedro Castle Formation and used to determine the morphology of the Pedro Castle dolomite along the north to south transect of the western peninsula of Grand Cayman.

The seven cores, arranged north to south (Figure 1.2) and named after their drilling location are:

Little Salt Creek (LSC1, LSC2)
Safe Haven (SH3)
Sewerage Works (SHT1, SHT2, SHT3)
Airport (ORA)

Partial core recovery is common for the seven cores. Missing core was recorded at the base of each core interval unless information indicated placement elsewhere. The 3.5cm diameter core was split where necessary, logged and sampled for thin sections. The thin sections were stained with Alizarin Red-S for calcite. Ferro-cyanide stains were not used as previous studies on Grand Cayman have shown the dolomites to be iron poor. A transmission light microscope was used to examine the thin sections.

Embry and Klovan (1971) modified Dunham's limestone classification system was used in describing the core and thin sections. This is a genetic classification system based on the textural (fabric) maturity of the rock, where rock fabric is believed to relate to depositional energy levels (Tucker and Wright, 1990). Rock fabric describes the relationships of allochems to one another and to the groundmass (if any).

Chapter 2: Sedimentology and Facies Architecture of the Cayman Formation

Facies in the Cayman Formation were delineated based on allochem content, texture, physical structures, and trace fossils. Allochem content was visually estimated from core and thin sections. Core colour is white to light tan, providing little contrast between matrix and allochems. The small diameter of the core means that volumetrically important, but widely spaced, allochems, such as large corals, may have been missed.

Dissolution and dolomitization pervasively altered the Cayman Formation and partially altered the Pedro Castle Formation. This diagenetic overprinting affects allochem preservation and obscures depositional fabric (Montpetit, 1998). Preferential preservation may have been as important as depositional conditions in determining relative abundance of observable allochems (Wignall, 1995). Facies delineation and paleoenvironmental interpretation are limited by these factors.

Grand Cayman was an isolated carbonate bank in an open ocean setting during the Middle Miocene when the Cayman Formation is thought to have been deposited (Perfitt and Heezen, 1978, Emery and Milliman, 1980; Jones et al, 1994). Topographic relief on the bank is suspected to be minimal (Brian Jones, pers. comm.). The study area is located on a leeward margin of Grand Cayman with respect to prevailing Miocene wind and current patterns (Nesbitt and Young, 1997; Iturralde-Vinent and MacPhee, 1999).

Skeletal Components

The fossil content is similar throughout the study area, changing mainly in the dominance of, not the presence of, specific allochems.

Corals are visually dominant in the Cayman Formation due to their large size. Branching corals (*Stylophora* spp. and *Porites baracoaensis*) are very common throughout the Cayman Formation. Branching coral fragments may also serve as the nuclei of large, elongate rhodoliths with thin coralline algal crusts. Laminar corals (*Leptoseris* and *Porites*) are locally common, whereas free-living solitary corals (*Trachyphyllia bilobata*) and massive colonial corals (*Montastrea limbata*) are rare.

Grains of crustose coralline red algae fragments dominate the fine-grained sediment component (< 2 mm) of the Cayman Formation. Identification of growth form and genera is limited due to fragmentation and diagenesis, but long slender branching forms and encrusting forms are present, as are the genera *Lithophyllum* and *Lithoporella*. Whole coralline red algae are rare. Fine-grained sediments commonly form the matrix between the larger allochems (> 2 mm) in the floatstones and rudstones.

Foraminifera and *Halimeda* are common fine-grained sediment components. The forams belong almost exclusively to the suborder Rotalina, with the benthic *Amphistegina* the dominant genus. Other rotalids include scattered *Sphaerogypsina* (benthic), mega *Amphistegina* (benthic), *Carpentria* (encrusting), and rare pelagic globorotalids. Forams belonging to the suborder Miolina are present but not common. A small number of unidentified biserial and uniserial forams are also present. Bivalves, echinoid fragments, and gastropods typically form 5-10% of any given facies, but may be more common locally. Bryozoans are rare.

Borings are ubiquitous in *Stylophora* molds, especially the sponge borings *Entobia* and *Trypanites* (Figure 2.1, 2.2). *Lithophagia* casts, made by boring bivalves, are rare (Pleydell, 1987). Few borings were found in other corals. Microborings (possibly fungal) are locally common in the bivalves. Microborings and serpulid worm encrustations are common in rhodoliths. Minor burrow mottling is present in the muddier facies; other burrow traces may have been obscured by diagenesis.

Nonskeletal allochems including intraclasts and peloids are rare. A high mud content may indicate the original presence of green algae. Possible biota such as seagrasses, worms, and benthic sponges that do not have calcareous skeletons are not preserved. As such they were not considered when defining facies, but their presence was considered when defining the environment of deposition.

Preservation of Skeletal Components

Coralline Algae

Coralline algae, originally composed of high-Mg calcite, are variably preserved. Clarity of the internal structure is variable. Small (~250μm), internally structureless, angular fragments of coralline algae are common in thin section (Figure 2.3, 2.4, 2.5,

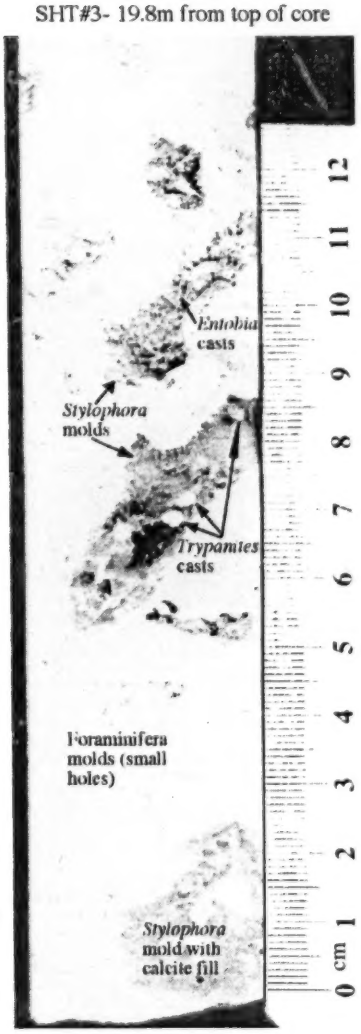

SHT#3- 19.8m from top of core
Entobia casts
Stylophora molds
Trypanites casts
Foraminifera molds (small holes)
Stylophora mold with calcite fill
0 cm 1 2 3 4 5 6 7 8 9 10 11 12

Figure 2.1

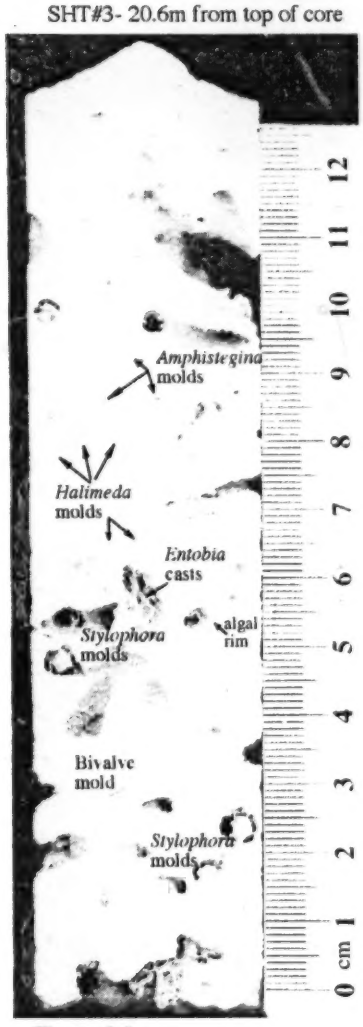


Figure 2.2

Stylophora facies association -Cayman Formation

Figure 2.1. Scanned core from the *Stylophora* facies with sparse coralline algae-*Amphistegina* wackestone matrix.

Figure 2.2. Scanned core from the *Stylophora-Halimeda* facies with sparse coralline algae, *Amphistegina* wackestone matrix.

Stylophora molds in both core samples show internal corallite molds and boring casts.

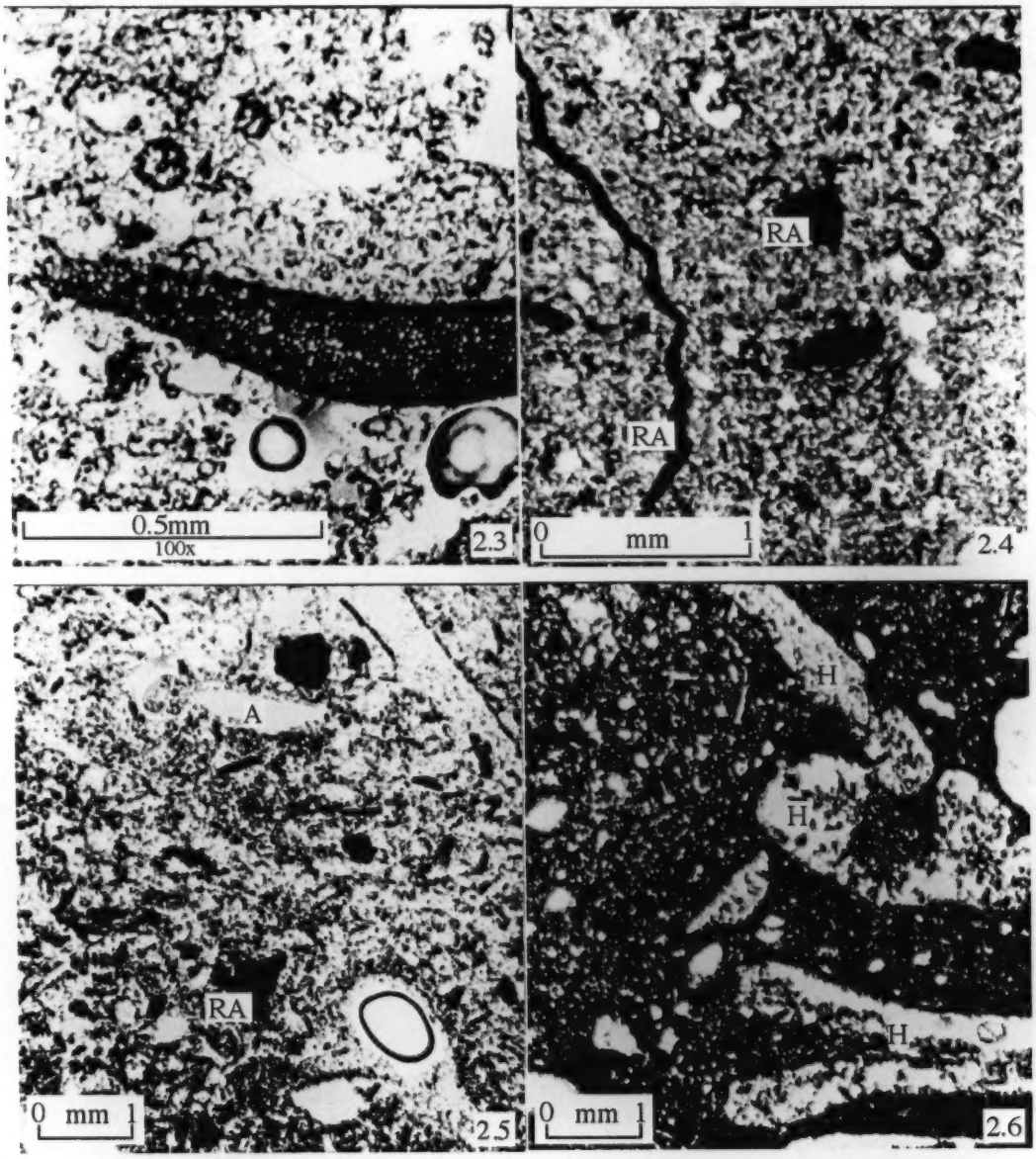


Figure 2.3. Photomicrograph of well preserved coralline algae (ORA-120').

Figures 2.4, 2.5. Photomicrographs of the porous coralline algal and *Amphistegina* wackestone matrix of various facies (LSC2-80'2",ORA1-25'11"). The brownish opaque masses (RA) are fragments of coralline algae. Dissolved *Amphistegina* (A) leave elliptical voids (infilled with resin to highlight porosity).

Figure 2.6. Photomicrograph of variably preserved *Halimeda* plates (H). Micrite filled utricles are often preserved within dissolved *Halimeda* plates (SHT1-117'5").

2.6). This preservation state may be due to the precipitation of high-Mg calcite within and between cell walls during early diagenesis, to which coralline algae are susceptible (Milliman, 1974; Scoffin, 1987). Dissolution and dolomitization have further altered the internal structures.

Foraminifera

Amphistegina are commonly dissolved, less commonly partially dissolved or mimetically replaced. This pattern of dissolution or replacement has also been observed in the Seroe Domi Pliocene Formation of the Netherlands Antilles (Sibley, 1982). Much of the elliptical shaped moldic porosity in the Cayman Formation is attributed to the dissolution of *Amphistegina* (Figure 2.5). Intermediate Mg-calcite *Amphistegina*, when not dissolved, are mimetically replaced so that internal structure and radial extinction patterns are preserved. Rotalids and globorotalids are usually mimetically replaced and preserved whole, or with minor fragmentation. The miliolid *Archais* is mimetically replaced and always severely fragmented.

Echinoids

High to intermediate-Mg calcite echinoid spines may be preserved as molds, but more commonly echinoids are found as fragments that have been pseudomorphically replaced by dolomite, retaining their distinctive unit extinction pattern under crossed polars. Syntaxial overgrowths are common.

Corals

Aragonitic allochems are leached or variably replaced. The Cayman Formation in the study area has very high moldic porosity. Large aragonitic corals are leached, leaving distinctive negative molds. *Stylophora*, *Montastrea*, and *Leptoseris* display characteristic corallite imprints due to fine sediment infilling of interseptal voids (Pleydell, 1987). Sediment infilling also preserves numerous boring casts in *Stylophora*. It is difficult to determine the degree of fragmenting of the branching, massive, and laminar corals due to the small diameter of the core. Jones and Hunter (1994b) noted that the branching corals are easily broken, although they did note many examples of *Porites* and *Stylophora* coral thickets in life position in outcrops of the Cayman Formation on Cayman Brac. Laminar corals show minor fragmentation in the core. Negative molds of solitary corals are of whole specimens.

Thin (~1 mm thickness) discontinuous rims of coralline algae encrustation are locally common on branching corals. Coral fragments that are entirely and heavily encrusted are classified as rhodoliths.

Green Algae and Molluscs

Halimeda and bivalves (aragonitic precursor) are commonly represented in core by thin, approximately 0.5 mm long molds. The molds of disarticulated *Halimeda* and bivalves are difficult to differentiate when small or fragmented. Large (>1 cm) articulated bivalve molds are rare. Dolomite replacement also occurs, and is variable (Figure 2.6). Gastropods are most commonly leached, leaving internal mud casts.

Light micrite rims are occasionally observed around allochems. In rare cases micrite rims remain as ghost structures around moldic porosity.

Facies of the Cayman Formation and their Interpretation

Nine facies have been identified (Table 2.1). Facies with similar biota that are found in close association are grouped into facies associations. These facies and facies associations are tied to six distinct depositional environments. Facies boundaries are gradational.

Similarities with facies from other Cayman Formation study sites on Grand Cayman and Cayman Brac have been noted. Coral distribution has been compared with that of the coral associations described by Hunter (1994) for the Cayman and Pedro Castle formations. Hunter (1994) delineated seven coral associations based on examination of numerous core and outcrop exposures on Grand Cayman and Cayman Brac – three of which are similar to the coral assemblages of the Cayman Formation in the study area.

***Stylophora* Facies Association**

Description

The *Stylophora* facies association is comprised of three *Stylophora* dominated facies: the *Stylophora* facies, the *Stylophora- Halimeda* facies and the *Stylophora*-bivalve facies (Figure 2.1, 2.2). These facies are extremely common, especially towards the top of the Cayman Formation in the study area (Figure 2.7).

Facies	Facies Description	Major Allochems	Minor Allochems	Non-Skeletal	Comments	Similar to:	Environment
Rhodolith-Foraminifera (RhF)	Rhodolith Floatstone with foraminifera dense **Wackestone to Packstone** matrix, rare **Grainstone**	*Amphistegina, Sphaerogypsina,* rhodoliths, *Halimeda, Trachyphyllia*	soritids, miliolids, *Carpentria,* bivalves, gastropods, coralline algae, echinoids, *Leptoseris , Porites, Stylophora,* globorotalids, green algae	(<1cm->5cm) rhodoliths-abundant intraclasts-rare	Same sized rhodoliths are grouped together; no overall pattern of distribution is recognized.	Wignall (1995)- Rhodolith-Foraminifera- *Halimeda* Pack-Grainstone Arts (2000)- Rhodolith-*Amphistegina -Trachyphyllia* Wackestone Hunter (1994)- Free-living Coral Association	High Energy Unconformity Colonization/ Unrestricted Lagoon
Trachyphyllia-Foraminifera-*Halimeda (TFH)*	*Trachyphyllia* Floatstone with foraminifera-*Halimeda* **Packstone** matrix, **local Grainstones**	*Amphistegina, Trachyphyllia, Halimeda*	soritids, miliolids, *Teleiophylla,* Sphaerogypsina, bivalves, gastropods, echinoids, coralline algae, *Thysanus, Stylophora, Montastrea, Carpentria*	small rhodoliths-rare	Laterally restricted uncommon facies.	Wignall (1995)- Solitary Coral-Foraminifera- *Halimeda* Wackestone Packstone	High Energy Unrestricted Lagoon
Foraminifera (F)	Foraminifera- skeletal fragment dense **Wackestone** to **Packstone, local Grainstone**	*Amphistegina, Sphaerogypsina*	soritids, mliolids, bivalves, *Halimeda,* coralline algae, echinoids, *globorotalids,* gastropods, *Trachyphyllia, Montastrea*	small rhodoliths	Limited diversity and abundance of biota.	Wignall (1995)- Foramin-ifera-Mollusc Packstone Arts (2000) Amphistegina-Rhodolith facies Packstone, local Grainstones Arts (2000) Bivalve-Foram-Halimeda-Rhodolith pack-wackestone, local grainstone	Fluctuating Energy Conditions-Restricted Lagoon
Foraminifera-Halimeda- Bivalve (FHB)	Foraminifera- *Halimeda*-bivalve **Packstone, local Wackestones** and **Grainstones**	Amphistegina, Sphaerogypsina, *Halimeda* , bivalves	soritids, miliolids, gastropods, *Carpentria* , echinoids, globorotalids, *Stylophora*	small rhodoliths-rare	Bivalves can be robust, with several mm thick shells.	Wignall (1995)- *Halimeda,* Mollusc Wackestone to Packstone	Moderate Energy Restricted Lagoon

Foraminifera-Mollusc-*Halimeda* (FMH)	Foraminifera- Mollusc-*Halimeda* **Wackestone** to **Packstone**	*Amphistegina* , *Sphaerogypsina* , bivalves, *Halimeda* , gastropods	soritids, miliolids, echinoids, *Styplophora, Montastrea, Trachypyllia,* globorotalids, *Leptoseris*	small-medium rhodoliths	Bivalves can be robust, with several mm thick shells.	Wignall (1995)-Mollusc, *Halimeda,* Foraminifera Wackestone to Packstone Arts (2000)-*Stylophora -Halimeda - Amphistegina* Wackestone to Packstone	Moderate Energy Restricted Lagoon
Foraminifera-*Halimeda (FH)*	Foraminifera- *Halimeda* **Packstone**	*Amphistegina, Sphaerogypsina, Halimeda,* soritids, miliolids	bivalves, gastropods, *globorotalids,* coralline algae, echinoids	small rhodoliths (<1 cm), small intraclasts-rare	Abundant *Halimeda* easily identifiable in core.	Arts (2000)- *Halimeda-Amphistegina* Wackestone to Mudstone	Moderate Energy Restricted Lagoon
Stylophora - Amphistegina (StF)	Stylophora Floatstone with *Amphistegina* **Wackestone** matrix	*Stylophora, Amphistegina*	*Halimeda,* bivalves, Porites, gastropods, soritids, miliolids, echinoids, coralline algae	small -medium rhodoliths	Uncommon facies, heavy diagenetic overprinting.	Wignall (1995)-*Stylophora,* Mollusc, Foraminifera Wackestone to Packstone Arts (2000)- *Stylophora-Halimeda-Amphistegina* Wackestone to Packstone	Low Energy Unrestricted Lagoon

Figure 3.1. Facies of the Pedro Castle Formation for the n-s western transect study area

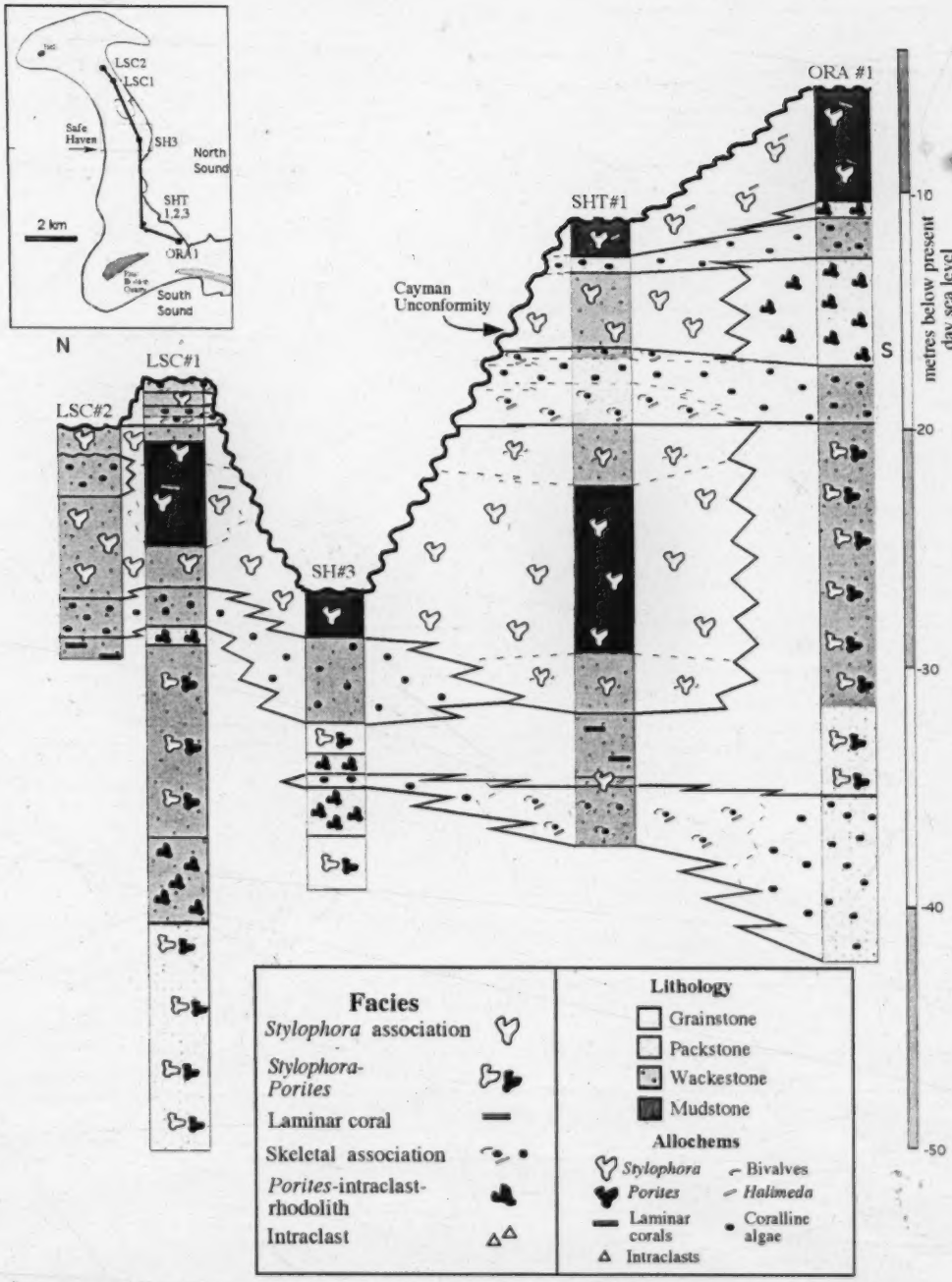


Figure 2.7. North-south cross section showing distribution of Cayman Formation facies on the western peninsula of Grand Cayman. Correlations are made where possible. The datum is present day sea level. Core recovery is very low below 40 m bsl for all wells.

Large (2 cm diameter) branching *Stylophora* spp. form 10-20% of the sediment volume in the *Stylophora* facies association. The *Stylophora* are variably orientated, commonly at oblique vertical angles, and are evenly distributed throughout. Much of the *Stylophora* material is broken, but unabraded, branches. Most of the corals appear to be in or near life position. Red algal encrustation is rare. The corals are heavily bored.

The matrix of the *Stylophora* facies association is muddy and usually dominated by coralline algae grains. Texture varies from mudstone to dense wackestone. Foraminifera, branches of *Porites baracoaensis,* and echinoderm fragments are minor components in all of the facies. Unfragmented laminar corals are rare in the *Stylophora* association; massive corals are very rare. Disarticulated, unfragmented to slightly fragmented *Halimeda* and bivalves are minor to major components.

The *Stylophora*-bivalve facies and the *Stylophora- Halimeda* facies are distinguished from the *Stylophora* facies by higher concentrations of bivalves and *Halimeda* plates (greater than 10%), respectively. Most of the bivalves are small and disarticulated, but large articulated bivalves are locally common. Increased numbers of bivalves are commonly associated with increased numbers of *Halimeda* plates. *Halimeda* plates in all three facies are commonly grouped with variable orientation.

Interpretation

The *Stylophora* facies association corresponds to Hunter's (1994) *Stylophora* association, which is found throughout the Cayman Formation. He suggested that *Stylophora* formed thickets in water 15-20 m deep. Established colonies of branching corals baffled local currents and caused sediment fallout from suspension. "Profuse growth of branching corals in muddy substrates under low-energy conditions was a common scenario throughout this phase of bank development" (Hunter, 1994). Wilson (1998) and Montpetit (1998) also described similar facies from eastern and south central Grand Cayman respectively.

Sparse coral cover and limited coral diversity in the *Stylophora* facies association can be explained by a high sedimentation rate (Jones and Hunter, 1994b). The species composition of modern Caribbean reef coral assemblages is related to a coral's efficiency at dealing with suspended sediment and coarse bottom traction material (Frost, 1977a).

Fine sediment covers and clogs coral polyps. Only those corals that grow rapidly enough to rise above the substrate or are able to remove sediment from their polyps can survive in an area with a high sedimentation rate (James and Bourque, 1992).

Certain branching corals, such as *Stylophora,* preferentially colonize muddy sediments and avoid colonization of coarse substrates (Jones and Hunter, 1994b; Wilson, 1998). The ramose form and limited surface area of branching corals minimizes fine sediment accumulation and elevates the coral polyps above muddy substrates. Material that settles on the corals is removed by tentacular movement or stomadeal distention of the polyps (Hubbard and Pocock, 1972; Jones and Hunter, 1994b; Wilson, 1998). The ramose branching coral skeleton requires comparatively less aragonite per unit skeleton than massive or encrusting corals (Frost, 1977b). This faster growth rate is a competitive advantage that allows branching corals to: grow above accumulating sediment; quickly recolonize areas cleared by storms, diseases, or other natural events, and repair areas damaged by predation.

Limited faunal diversity may also be related to static depositional conditions Frost, 1977a). Environmental conditions that remain constant over extended periods of time can produce static communities in which individual species are able to exploit their competitive advantages and gain dominance. The *Stylophora* facies association is present in extensive vertical sections (up to 17 m thick) that suggest prolific sediment production and depositional conditions that were stable over long periods. This stability includes storms and subsequent recolonizations of storm affected areas.

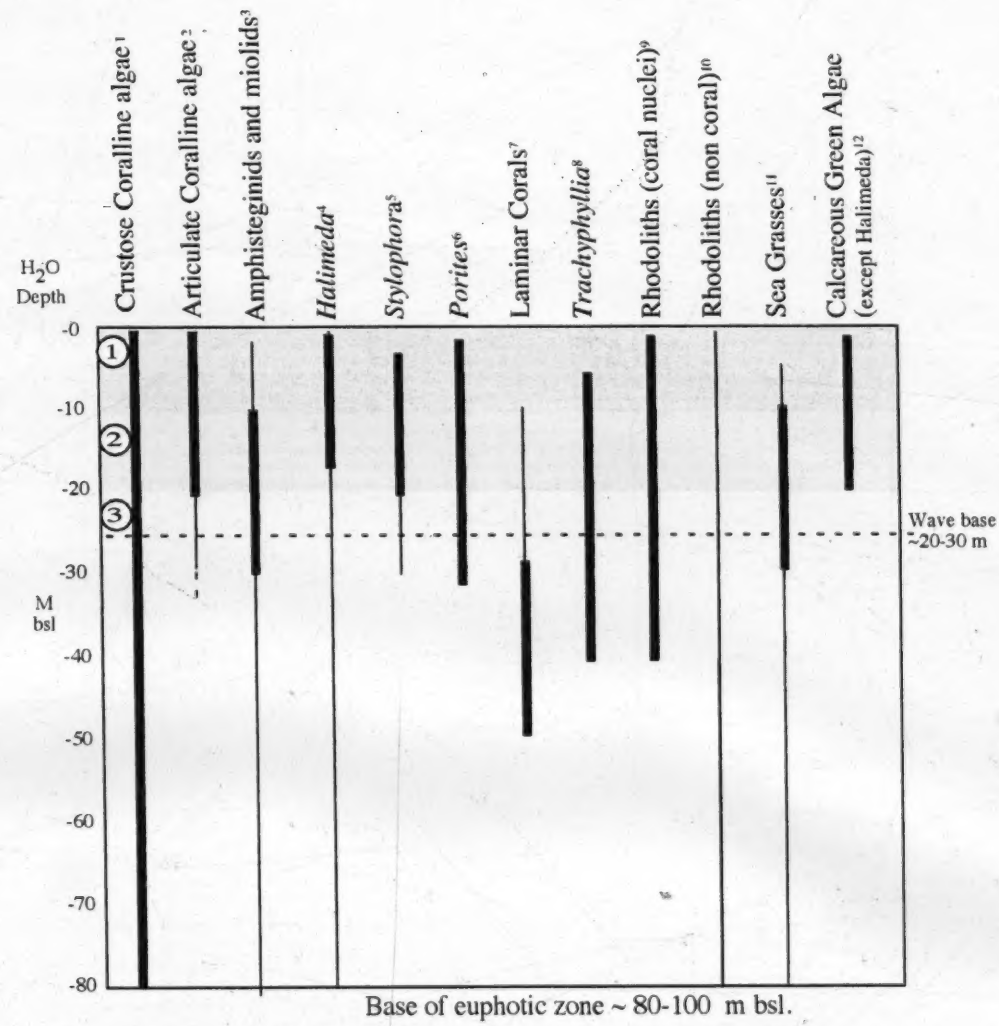
A muddy substrate facilitated initial *Stylophora* growth, but baffling of currents and stabilization of the substrate would have led to further accumulation of fine-grained sediment. Bioerosion by boring sponges would have produced substantial amounts of silt-sized chips that may have been reduced to lime mud through subsequent bioerosion by algae and fungi (Warme, 1977; Pleydell, 1987). This would also have increased the local sedimentation rate, making the environment less hospitable to corals inefficient at sediment rejection.

Modern branching corals are unstable in rough waters, and are most common in low energy shallow to moderately deep forereef localities (James and Bourque, 1992). The lowest disturbance levels on modern reefs are found at depths of 15-20 m (Budd et

al, 1989). In the Oligocene, *Stylophora* was common on the lee side of patch reefs, the deeper parts of fringing reefs and fore reef environments (Frost, 1977a). By the Late Miocene however, *Stylophora* occupied a similar ecological niche as *Acropora cervicornis* on modern day reefs (Frost, 1977b; Gill and Hubbard, 1985). Thickets of *Acropora cervicornis* have colonized patch reef tops on modern Grand Cayman's low-energy leeward margins (Roberts and Sneider, 1982). This would indicate an optimum depth range of 3-20 m, and a maximum depth of about 30 m bsl (Liddell and Olhurst, 1987; Porter, 1987).

Less exact are the estimated depths of the associated algal and foraminifera assemblages (Figure 2.8). Flora such as coralline algae and Codiaceans are most common in shallow water, but exist throughout the photic zone (Wray, 1977; Milliman, 1991). Jones and Hunter (1994b) noted that rhodoliths with coral nuclei are most common in waters less than 40 m deep, although this may be more a function of availability of coral nuclei than nuclei preference in a certain depth zone.

The foraminifera assemblage is dominated by robust, algal symbiont bearing benthonic forms typical of shallow water environments (Milliman, 1974; Chaproneire, 1975; Li, 1997). *Amphistegina* is a common Caribbean reefal taxon, characteristic of reef, near reef, and bank biotypes. Li (1997) found that living *Ampistegina gibbosa* were most abundant on modern Grand Cayman's windward forereef terraces in water deeper than 10 m. It was also prominent in Grand Cayman's high energy, leeward nearshore assemblages. *Amphistegina* has a flat lenticular test, and is commonly found as an epibiont on sea grasses and hard substrates, although it is also common in loose sediment (Crouch and Poag, 1979). Estimates of habitat depth range from < 35 m (Chaproneire, 1975), < 40 m (Rezak, 1977), < 50-60 m (Larsen, 1976), to < 100m (Crouch and Poag, 1975; Poag and Tresslar, 1981). Seiglie and Mousa (1975,1981) considered a high percentage of *Amphistegina* indicative of a fore-reef paleoenvironment, and Moussa et al. (1987) interpreted a water depth of 10-35 m for the upper member of the Pliocene Quebradillas limestone of northwestern Puerto Rico based on the dominant presence of *Amphistegina* and coralline algae. Less common large miliolids are found at depths < 30 m bsl (Chaproneire, 1975). Empty foraminifera tests may be transported to shallower or deeper waters (Seiglie and Mogussa, 1975; Rezak, 1977, Li, 1997). The dominance of



1	0-10m	Schlager's (1981) zone of maximum carbonate productivity
	5-20m	Highest Coral Diversity (Goreau, 1963)
2	10-20m	Maximum carbonate productivity drops by a factor of 2 (Glaser, et al., 1991)
	15-20m	Lowest levels of disturbance (Budd et al, 1989)
3	0-45m	Zone of optimum hermatypic coral growth (Minnery, 1990)
	>40 m	Coralline algae are the dominant frame builders (Minnery, 1990)

1. Johnson, 1961; Milliman, 1974; Scoffin, 1987; Boscence, 1991
2. Johnson, 1961; Goreau, 1963; Milliman, 1974; Scoffin, 1987
3. Larsen, 1976; Poag and Tesslar, 1981; Venec-Peyre, 1991
4. Wray, 1977
5. Frost, 1977b; Porter, 1987
6. Foster, 1986
7. Liddell and Olhorst, 1987; James and Bourque, 1992; Hunter, 1994
8. Hunter, 1994
9. Jones and Hunter, 1994b; Reid and Macintyre, 1988; Boscence, 1983
10. Littler, 1991
11. Domning, D.P., 2001 (Pre-Pliocene seagrass beds may have been more abundant in deeper waters than today)
12. Wray, 1977

Figure 2.8. Biota distribution with depth.

robust, abrasion resistant forms may be partly an artifact of preservation, as more delicate forms are easily fragmented (Marshall, 1976; Martin and Wright, 1988; Li, 1997). Wignall (1995) and Wilson (1998) cited amphisteginid and miliolid dominated sediments as evidence of deposition in unrestricted waters between 10-30 m bsl.

Variations in the amount of *Halimeda* plates and bivalve shells may be related to localized variations in substrate, light penetration, energy levels, or water temperature (Wiman and McKendree, 1975). The clustered *Halimeda* plates and lack of abrasion indicates minor transport by suspension and saltation (Basan, 1977). The bivalves may have preferentially lived in green algal clumps. Sea grasses may also have been present.

A depositional depth of 10-30 m bsl, but probably < 20 m, is indicated by the faunal evidence and the leeward location of the study area. Variations in matrix texture are attributed to winnowing by storm currents. Winter storm waves and hurricanes would have fragmented the *Stylophora* corals, especially those made susceptible by high levels of bioeroision. This fragmentation may have promoted the formation of new colonies (Porter, 1987; Roberts and Sneider, 1982). Boring of the branches would have continued until the corals were entirely buried or encrusted (Warme, 1977). Rare, thin, uniform algal crusts on coral branches indicates dead corals remained on the surface of a single habitat for a short period of time before becoming buried by sediment and out of reach of encrusters (Martindale, 1992).

In summary, the *Stylophora* facies association was deposited in a stable, shallow bank environment characterized by low energies, high sedimentation, and periodic storm disturbance. The corals formed sparse thickets that baffled currents and contributed to the fine- grained character of the facies. Depositional depth was between 10 and 30 m bsl, but most commonly < 20 m bsl.

***Stylophora-Porites* Facies**

Description

This facies (Figure 2.9) has the highest coral diversity and fragmentation in the study area. The relative coral abundance is *Stylophora* spp.> *Porites baracoaensis*>> *Leptoseris* sp. A>> *Trachyphyllia bilobata* >> *Montastrea*. The percent volume of core occupied by corals is 10-20%, and is more variable than in the *Stylophora* facies

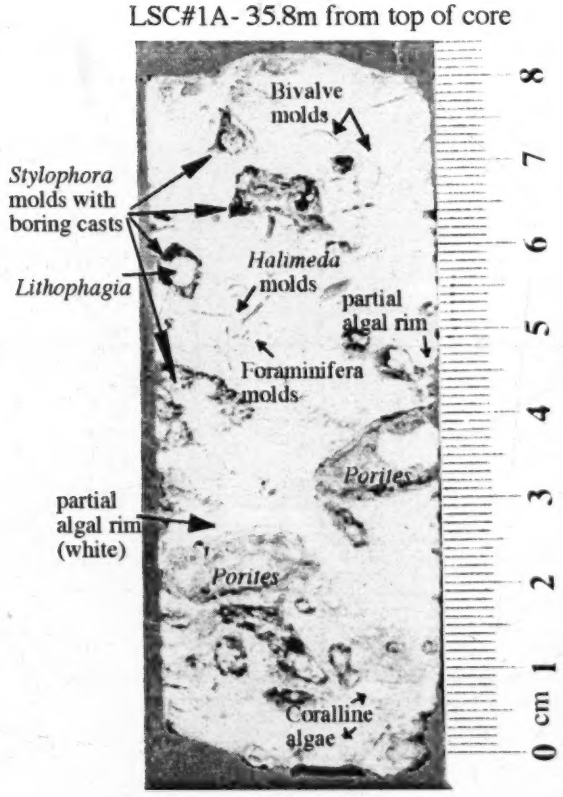


Figure 2.9

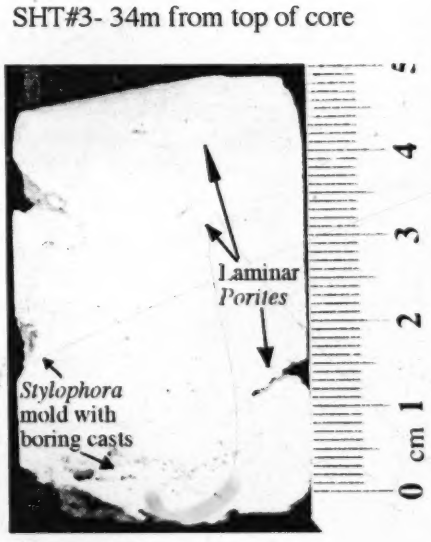


Figure 2.10

Cayman Formation

Figure 2.9. Scanned core from the *Stylophora-Porites* facies.

Figure 2.10. Scanned core from the Laminar coral facies.

association. In situ *Stylophora* are rare. The *Stylophora* branches are generally smaller than in the *Stylophora* facies association, and show minor abrasion. The orientation of the *Porites* branches is dominantly oblique to horizontal. *Porites* has been fragmented along its length, and is therefore relatively unabraded in cross-section. *Leptoseris* appear to be in situ. Thin (1-2 mm) coralline algae encrustations are locally common on the branched corals; a small number are entirely encrusted. These are classified as rhodoliths, and are approximately the same size and shape as the coral fragment, but with a thin algal rim.

The matrix is a coralline algae and *Amphistegina* dominated wackestone to packstone; *Halimeda* plates and molluscs are common.

Interpretation

Increased coral diversity, fragmentation, and a coarser texture relative to the *Stylophora* facies association indicate that the branching coral facies represents a higher energy environment. Energy levels were high enough to displace and fragment *Porites*, and to overturn a small number of the fragments so that complete coralline algal encrustation could occur. However, fragmentation was not severe, and rare in situ *Stylophora* and laminar corals indicate subdued wave energies. Laminar corals and rhodoliths indicate low sedimentation rates. The large surface area of the laminar corals makes them susceptible to sediment accumulation (Tucker and Wright, 1990), whereas sediment can bury rhodoliths, killing the phototrophic encrusting coralline algae (Montpetit, 1998).

Hunter (1994) reported a *Stylophora-Porites* coral association in the Cayman Formation that typically formed small patch reefs with a high coral density (30-40%). Mixed branching coral associations with varying numbers of rhodoliths and massive corals have been reported from eastern and south central Grand Cayman (Montpetit, 1998, Wilson, 1998).

The coral fauna, rhodoliths, and coarse matrix texture indicates an environment above storm base with moderate energy levels and sedimentation rates in water less than 20 m deep.

Laminar Coral Facies

Description

Laminar corals (*Leptoseris* sp. A and *Porites*) with scattered *Stylophora* spp. branches and crustose coralline algae crusts characterize the laminar coral facies (Figure 2.10). These allochems form 10-15% of the facies. The laminar corals and crustose algae are unfragmented to lightly fragmented. The matrix varies from a sparse to dense coralline algae and *Amphistegina* wackestone. *Halimeda* is a minor component; bivalves and gastropods are rare.

Interpretation

The flattened shape and large surface area of the laminar corals and crustose algae allows optimal light intake (Goreau, 1963) and increases their stability in strong currents (Wilson, 1998). The morphology, however, is unsuited for areas of high sedimentation (Jones and Hunter, 1994b), high wave energy (Tucker and Wright, 1990), or unstable environments. Modern flat lying corals typically occupy environmental niches below 30 m (Tucker and Wright, 1990; James and Bouroque, 1992). Intermixing with *Stylophora* branches and the sparseness of the laminar corals indicates shallower conditions (Jones and Hunter, 1994b). A depth below wave base (Liddel and Olhurst, 1987; James and Bourque, 1992) is generally proposed for this facies, although it may also be found in shallower waters in current swept shaded areas, under overhangs, spur margins, and between reefs (Hunter, 1994). Hunter (1994) described a similar *Leptoseris* coral association (but with a denser packstone matrix and more diverse coral fauna) that passed laterally into the *Stylophora* association, indicating close depositional proximity of the two environments (Wilson, 1998).

The Laminar coral facies is interpreted as having been deposited in a low light, low sediment, low-moderate energy environment between 20-30 m. The substrate was partially stabilized and the area was swept by currents.

Skeletal Facies Association

Description

Small (~ 250 μm) grains of crustose coralline red algae fragments dominate the coralline algae-*Amphistegina* facies (Figure 2.11). Amphisteginids are common, and show little fragmentation. Molluscs, coral fragments, forams (*Sphaerogypsina*, miolinids, and rare Globorotalids), *Halimeda* plates, and echinoderms fragments are scattered throughout. The coralline algae-*Halimeda-Amphistegina*-Bivalve facies is similar, but has *Halimeda* and bivalves as major allochem components (greater than 10%) (Figure 2.12).

Micrite envelopes exist on many allochems; sometimes remaining after the allochem has been dissolved. Burrow mottling is locally common. Short (several cm) intervals of low angle (~30^0) cross laminations are very rare.

Interpretation

The wackestone to packstone texture indicates intermediate energy levels, and possible winnowing of mud. A general lack of cross-bedding may be a result of insufficient energy to induce shifting of sediments. It is also possible that energy levels were sufficient to move loose sediment, but that bioturbation destroyed evidence of cross-bedding, or that cross-beds never formed due to a stabilized substrate. It is also possible that bed forms are present, but of too large a scale to be seen in the small diameter core (Wignall, 1995).

A lack of corals may be due to a poor coral recruitment or conditions unsuited for coral growth. Corals are environmentally sensitive and live within narrow ranges of light penetration, water circulation, temperature, salinity, and oxygenation. (Jones and Desrochers, 1992; Wilson, 1998). Jones and Hunter (1994b) found that substrate conditions heavily influenced coral distribution in the Cayman Formation on Cayman Brac. Branching corals, which dominate the coral fauna in the study area, were preferentially found in muddy substrates, suggesting that coarser substrates were unsuitable for branching coral growth (Jones and Hunter, 1994b; Wilson, 1998). It may also be that the substrate is unstable, similar to the rapidly deposited and reworked drift current sediments on the modern lee side of Grand Cayman (Roberts and Sneider, 1982). Reworking of the sediment may also have destroyed cross-beds. The skeletal wackestone

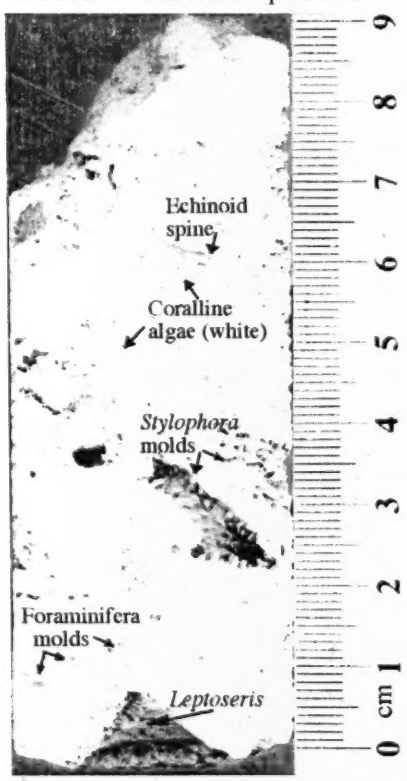


Figure 2.11

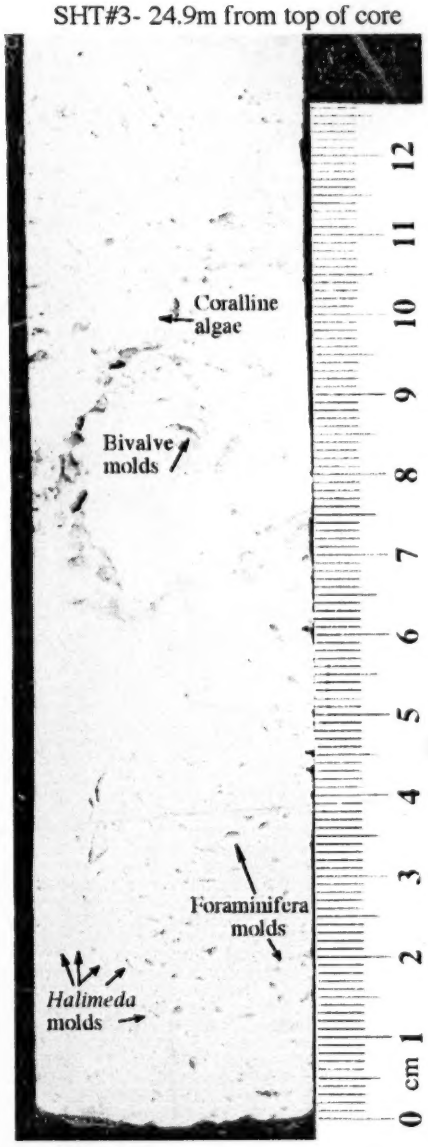


Figure 2.12

Skeletal facies association- Cayman Formation

Figure 2.11. Scanned core of the coralline algae-*Amphistegina* facies with coral fragments. Negative molds of corallites are visible in the *Stylophora* molds.

Figure 2.12. Scanned core of the coralline algae-*Halimeda*-*Amphistegina*-bivalve facies. Mottling and concentric alignment of allochems are evidence of bioturbation.

to packstone facies are found in vertically confined, laterally extensive intervals, suggesting depositional conditions that existed on a regional scale.

The allochem content of the facies is typical of fine unconsolidated sands, which are characterized by numerous calcareous algae, forams, and fewer mollluscs and echinoids (Goreau, 1963; Venec-Peyre, 1991). The skeletal facies association is similar in biota to the three skeletal packstone to grainstone facies, interpreted as a sand plain environment, that dominate the Cayman Formation in the Safe Haven area (Wignall, 1995). Wignall (1995) proposed that the original matrix of packstone and wackestone textures in the Cayman Formation of the Safe Haven area (Figure 1.2) may have originally been characterized by silts rather than muds. This is based on the observation that silts characterize the modern lagoons and shallow forereef environments on Grand Cayman. This may also be true for the study area.

In summary, the skeletal wackestones to packstones were deposited in a moderate energy, shallow water environment. The substrate may have been unstable and too coarse to support extensive branching coral growth. This environment may be analogous to a muddy sand plain.

Porites-Intraclast-Rhodolith Facies

Description

Variously orientated fragments of *Porites baracoaensis*, small, subrounded intraclasts (< 2 cm), rhodoliths, *Halimeda,* and coralline algae are in grain to grain contact (Figure 2.13, 2.14). *Stylophora* fragments are locally common. The intraclasts are fragments of dense coralline algae packstones with minor *Amphistegina,* similar to the coralline algae and *Amphistegina* facies. Large (<1 cm to several cm) rhodoliths have branching coral nuclei and a thin and uneven encrustation of coralline algae. The morphology of the rhodolith reflects the shape of the coral fragment. Small (>1 cm) rhodoliths with intraclast or skeletal fragments as nuclei are also common. *Porites* branches commonly have oblique vertical orientations, differing from the usual horizontal orientation. Fragmentation is more severe than in other facies, and abrasion is apparent in cross-section. The matrix is a variable combination of coralline algae and

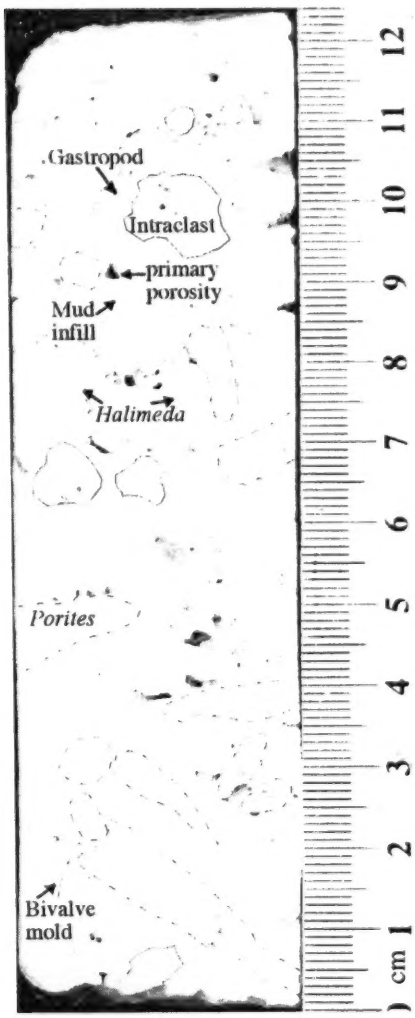


Figure 2.13

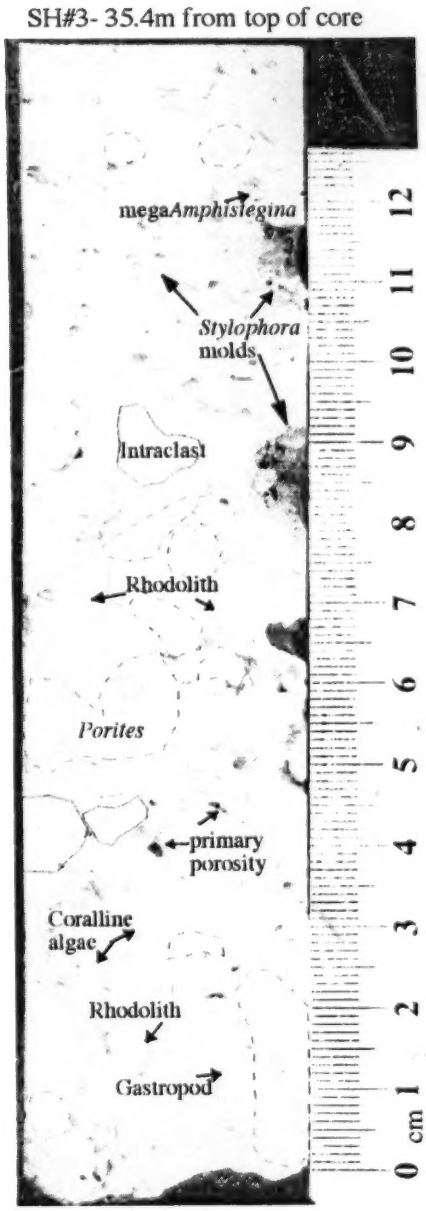


Figure 2.14

Cayman Fomation

Figure 2.13, 2.14. Scanned core of the *Porites*-intraclast-rhodolith facies. The matrix varies from grainstone to mud fill. Minor primary shelter porosity is perserved below large allochems. Dashes outline *Porites* fragments. Solid lines surround lithoclasts.

Amphistegina dense wackestone to packstone to grainstone with mud fill. Minor primary porosity remains protected beneath large allochems.

Interpretation

The density and orientation of the *Porites* branches and the preservation of primary porosity below the branches suggests deposition under high-energy conditions. Allochems characteristic of high-energy conditions, such as intraclasts and rhodoliths are also common. These conditions were short lived, as evidenced by the mud matrixes.

The high proportion of *Porites* fragments relative to *Stylophora* fragments was not observed elsewhere in the study area. The most similar facies with respect to the volume of *Porites* material is the branching coral floatstone facies, which is closely associated with the *Porites*-intraclast-rhodolith rudstone facies. The large number of *Porites* branches indicates proximity to a *Porites* buildup. A *Porites* reef was identified between 20 m bsl and 33 m bsl in the western peninsula of Grand Cayman, trending N-S through the Safehaven area (Wignall, 1995). The Safehaven reef is stratigraphically too shallow and too far away to be the source of the Porites fragments, but its presence may indicate other *Porites* buildups to the west of the study area.

The *Porites*-intraclast-rhodolth facies was deposited by localized, high-energy conditions. This facies may represent storm debris from a *Porites* reef or thicket.

Intraclast Facies

Description

High numbers of intraclasts and skeletal fragments define this facies (Figure 2.15, 2.16). They are white, subrounded to rounded, and 1 mm-20 mm across (mode of ~3 mm). Matrix texture varies from wackestone to grainstone. Facies boundaries are not sharp.

Laminar coral fragments and coralline algae nodules are abundant. Intraclasts are dark mudstones and wackestones made up of coralline algae, rotaliids, peloids and bivalves. Diagenesis has obscured the allochems in the intraclasts. This facies was only found in SHT#3 (Figure 2.17).

SHT#3- 31.7m from top of core

Figure 2.15.

Cayman Formation

Figure 2.15. Scan of porous core with sub-rounded intraclasts and skeletal fragments.

Figure 2.16. Photomicrograph showing subrounded *Porites* fragments and intraclasts.

SHT#3- 31.7m from top of core

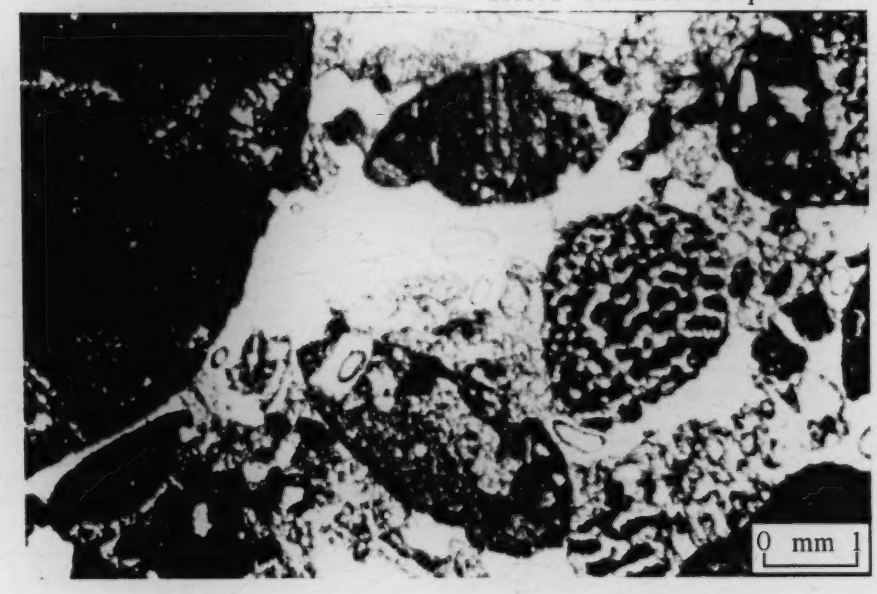


Figure 2.16.

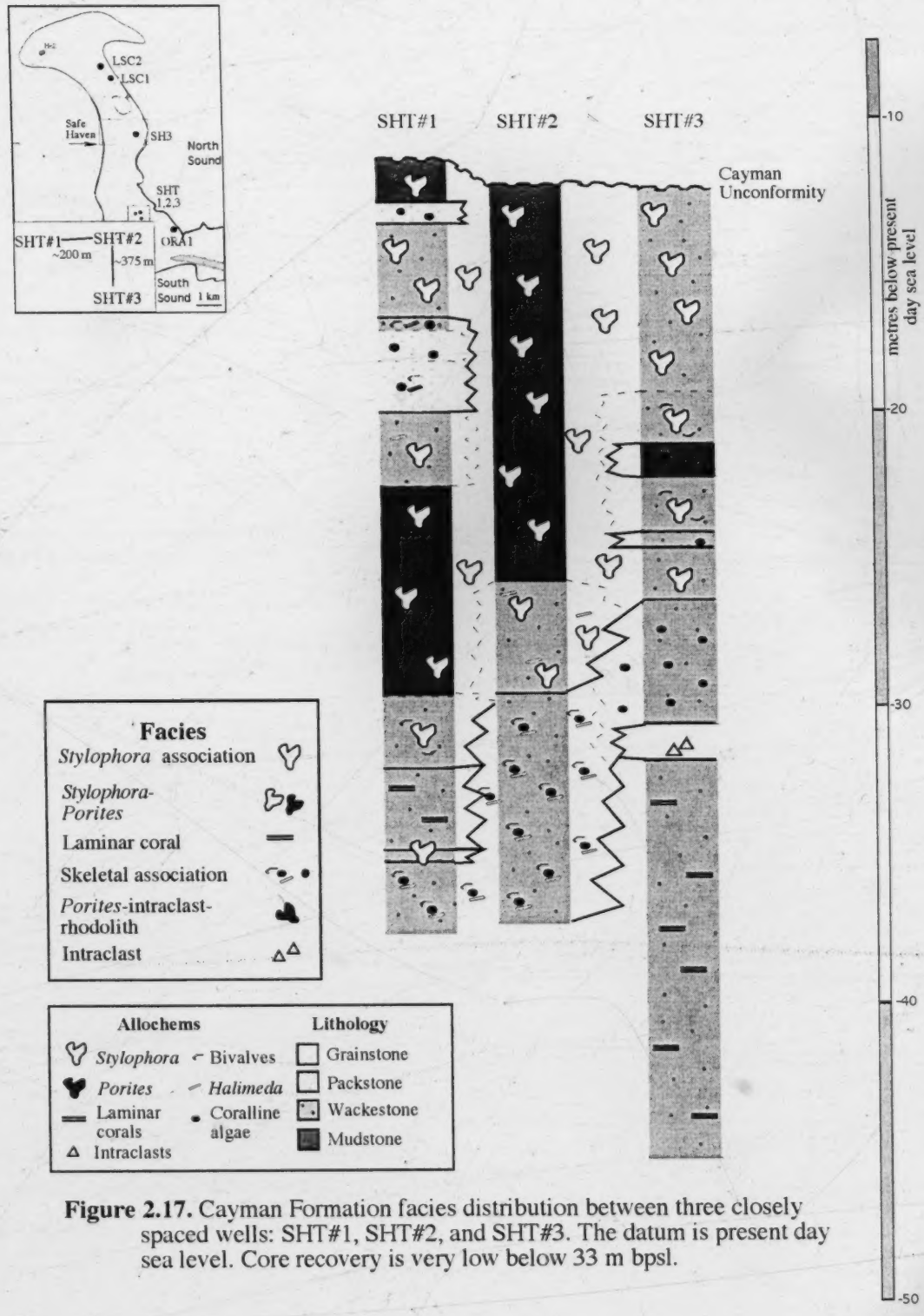


Figure 2.17. Cayman Formation facies distribution between three closely spaced wells: SHT#1, SHT#2, and SHT#3. The datum is present day sea level. Core recovery is very low below 33 m bpsl.

Interpretation

Subrounded to rounded intraclasts and skeletal fragments indicate erosion and extended transport of previously deposited material. Deposition was the result of a storm event. The material appears to have been derived from a facies similar to the underlying laminar floatstone facies. Hardgrounds were not observed in SHT#3 or surrounding wells, although this may be a function of poor core recovery. Gradational boundaries and variable matrix textures suggest initial protection from scouring, perhaps a low spot in which material collected.

Facies Architecture

The Cayman Formation in the study area (N-S western transect) can be divided into two depositional units that represent distinct depositional regimes (Figures 2.18, 2.19). The lower unit, depositional Unit I, is primarily composed of the *Porites*-intraclast-rhodolith facies, branching coral facies, intraclast facies, and the laminar coral facies. The upper unit, depositional Unit II, is composed exclusively of the *Stylophora* facies association. The skeletal facies association is found in both units, as it forms laterally extensive intervals throughout the Cayman Formation.

Depositional Unit I

Depositional Unit I extends from the base of each well up to ~30 m bsl, with the exception of the southernmost well ORA#1 where it is present up to ~10 m bsl. Recovery is commonly poor at the base of the wells.

The laminar coral facies is located at the base of wells LSC#2 and SHT#3. In SHT#1 it overlies a thin interval of the *Stylophora* facies. The laminar coral facies is not found in wells that contain the branching coral and *Porites*-intraclast-rhodolith facies. Directly overlying the laminar coral facies in well SHT#3 is the only interval of the intraclast facies (1.5 m thick) in the study area. The branching coral facies is the most common facies in depositional Unit I. It alternates with thinner intervals of the *Porites*-intraclast-rhodolith facies in wells LSC#1, SH#3, and ORA#1. The branching coral and *Porites*-intraclast-rhodolith facies extend up to ~10 m bsl in well ORA#1.

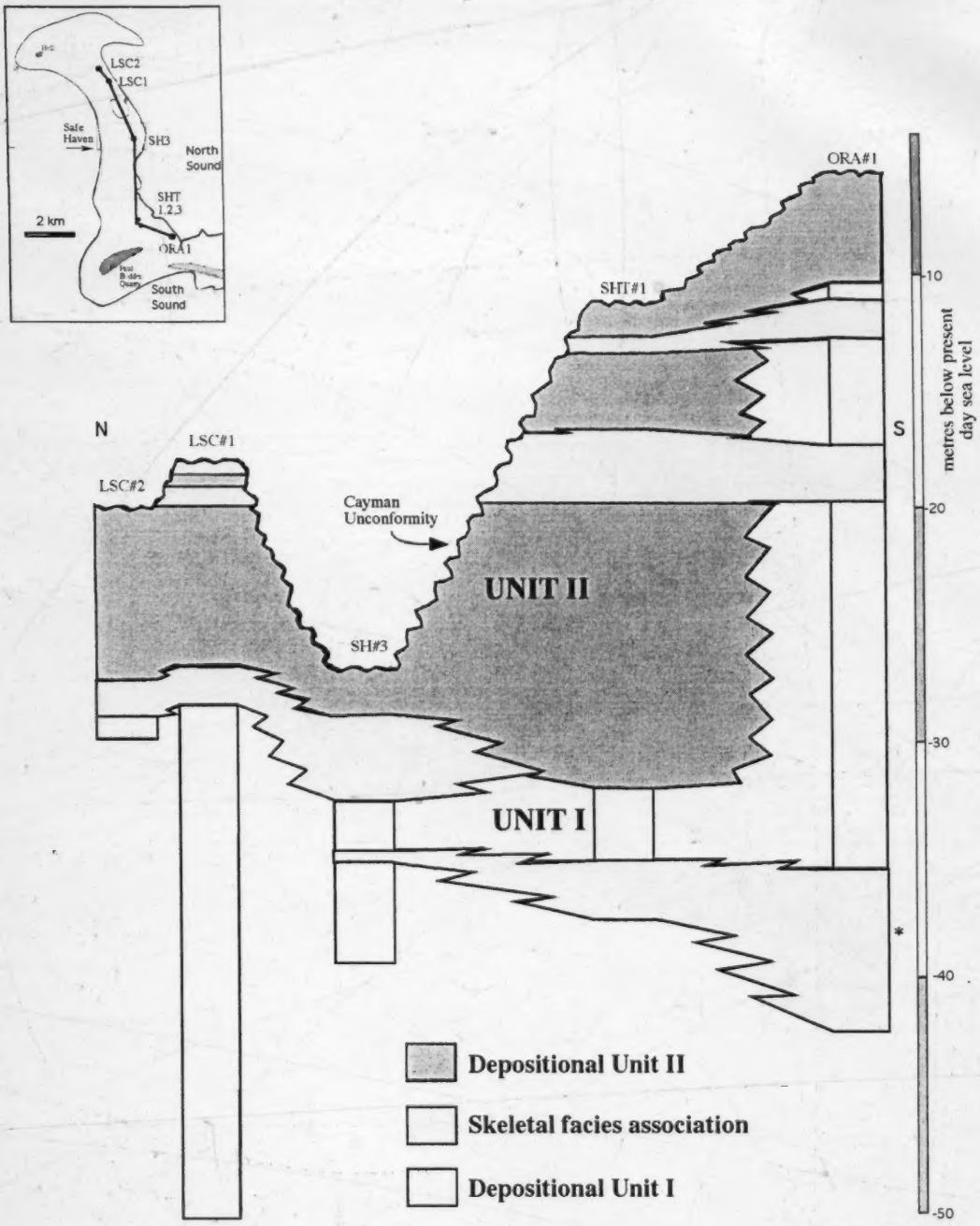


Figure 2.18. Depositional Units I and II of the Cayman Formation. The Skeletal facies association forms laterally extensive intervals in both units.

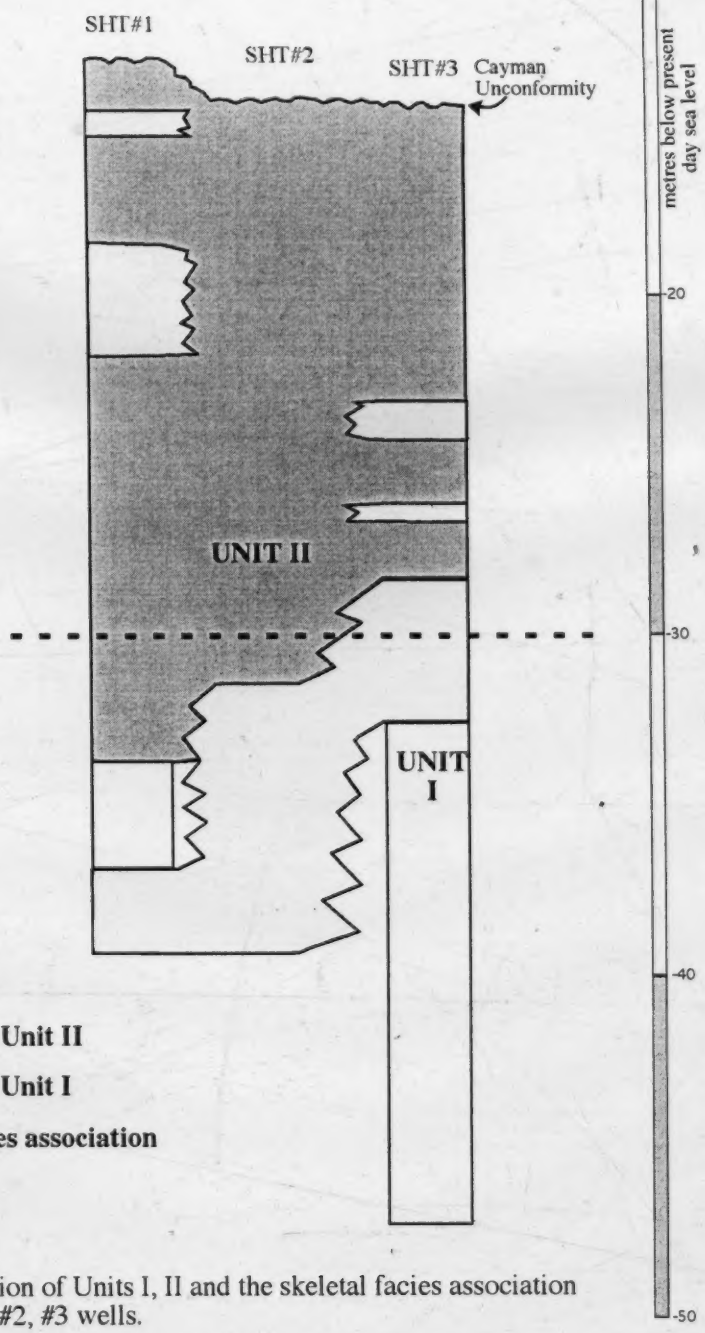


Figure 2.19. Distribution of Units I, II and the skeletal facies association in the SHT#1, #2, #3 wells.

The facies of depositional Unit I are characterized by displaced branching corals (*Porites baracoaensis* and *Stylophora* spp.), scattered in situ laminar corals, and rhodoliths. Massive corals are rare. The facies are not laterally extensive and correlation between wells is difficult. Wackestones and packstones matrix textures are common, whereas intervals of grainstones are rare.

Depositional Unit II

Depositional Unit II dominates the upper part of the Cayman Formation in the study area. It extends from ~30 m bsl to the Cayman Unconformity (with the exception of the southernmost well ORA#1). The unconformity is an erosional boundary that cuts deepest into the central and northern wells. The upper 2 m of depositional Unit II is commonly well cemented and case hardened.

The *Stylophora* facies association is found in every well in the study area and can be correlated between wells. Uninterrupted intervals of the association may be more than 15 m thick. Facies of the association interfinger without a discernible pattern. The *Stylophora* facies is the dominant facies; the *Stylophora-Halimeda* and *Stylophora*-bivalve facies are less common.

The *Stylophora* facies association is characterized by in situ *Stylophora* held in a coralline algae matrix. Facies variability and coral diversity is low. Matrix texture varies from mudstone to wackestone.

A relationship appears to exist between the matrix texture and the type of branching coral in the study area. Wackestones and mudstones are dominated by evenly distributed in situ *Stylophora* spp., whereas packstones and grainstones commonly contain dense concentrations of *Porites baracoaensis* fragments.

Skeletal Facies Association

The skeletal facies association can be traced laterally along parts of the western transect at approximately 12 m, 19 m, 30 m, and 37 m bsl (Figure 2.18). These correlations however, cannot be traced between the closely spaced SHT wells (Figure 2.19). The coralline algae- *Amphistegina* and the coralline algae- *Halimeda-Amphistegina*-bivalve facies interfinger with no discernible pattern.

Water depth versus Water Energy

Facies variability is common in the Cayman Formation, especially in the lower depositional unit. Textural differences exist within and between each unit. Water depth, however, was between 10 and 30 m for every facies. More exact water depths are difficult to determine as they are based primarily on the habitat depths of biota which are often broad and/ or undetermined. Biota may also change in response to environmental fluctuations which are unrelated to water depth, be transported away from their depositional site, or be affected by diagenesis (Scoffin, 1987; Jones and Desrochers, 1992). Static water depths throughout deposition of the Cayman Formation indicate that sediment accumulation kept pace with increases in relative sea level. This suggests that increases in relative sea level were minimal and that a highstand position may have been reached.

Currents, waves, tides, and fluctuating sea levels influence depositional energy levels. Energy fluctuations without corresponding fluctuations in water depth indicate that water energy is independent of water depth (Figure 2.20). Facies variability in the Cayman Formation is therefore a reflection of varied energy levels. Different energy levels existed in different locations during deposition of Unit I. Energy levels decreased and became similar throughout the study area during deposition of Unit II. This implies a change in current or wave activity.

Comparisons with other Cayman Formation studies

Previous studies of the Cayman Formation include those at Safe Haven (Wignall 1995), Tarpon Springs Estates (Montpetit, 1998), Roger's Wreck Point (Wilson, 1998) and Cayman Brac (Jones and Hunter, 1994b). There is no evidence of a regional dip on Grand Cayman, and all of the Grand Cayman study locations are at similar stratigraphic depths as the study area (Figure 2.21). The Cayman Formation on Grand Cayman is tentatively thought to correlate mainly with the middle and upper parts of the Cayman Formation on Cayman Brac (B. Jones, pers. comm.).

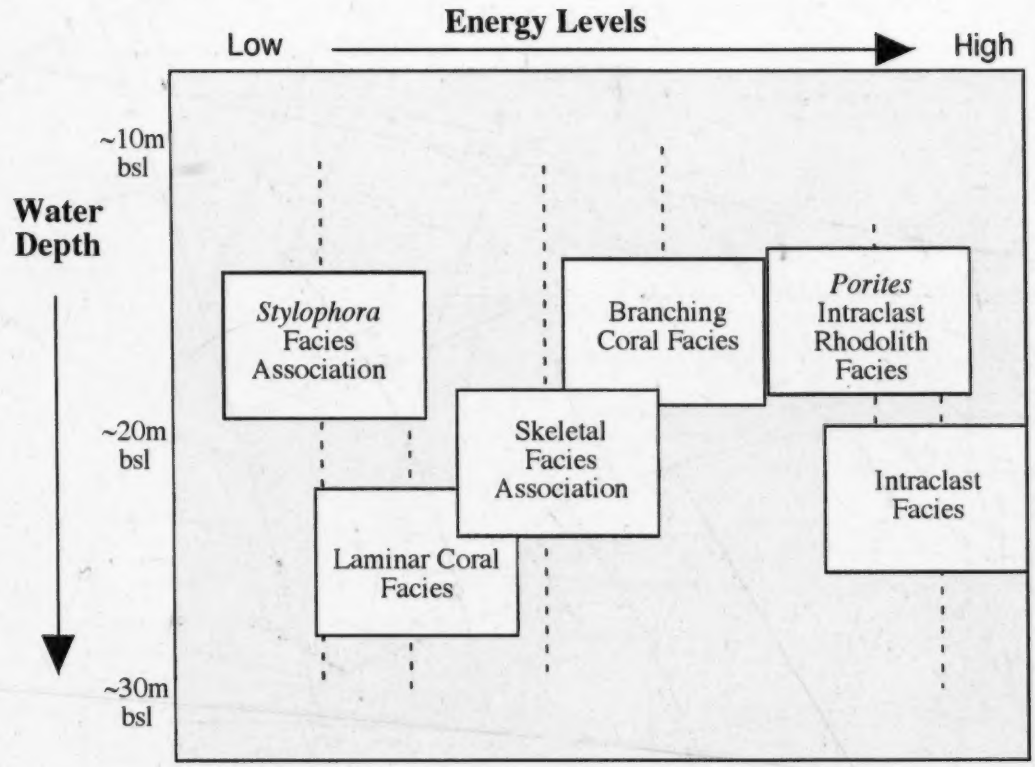


Figure 2.20. The influence of water energy versus water depth is examined for the facies of the Cayman Formation. Increasing energy levels do not correlate with decreasing water depths. There is not a constant or appreciable change in water depth during deposition of the Cayman Formation, whereas there are wide fluctuations in energy levels. This suggests that the variables are independent of one another, and that facies variability in the Cayman Formation is a result of fluctuating energy levels.

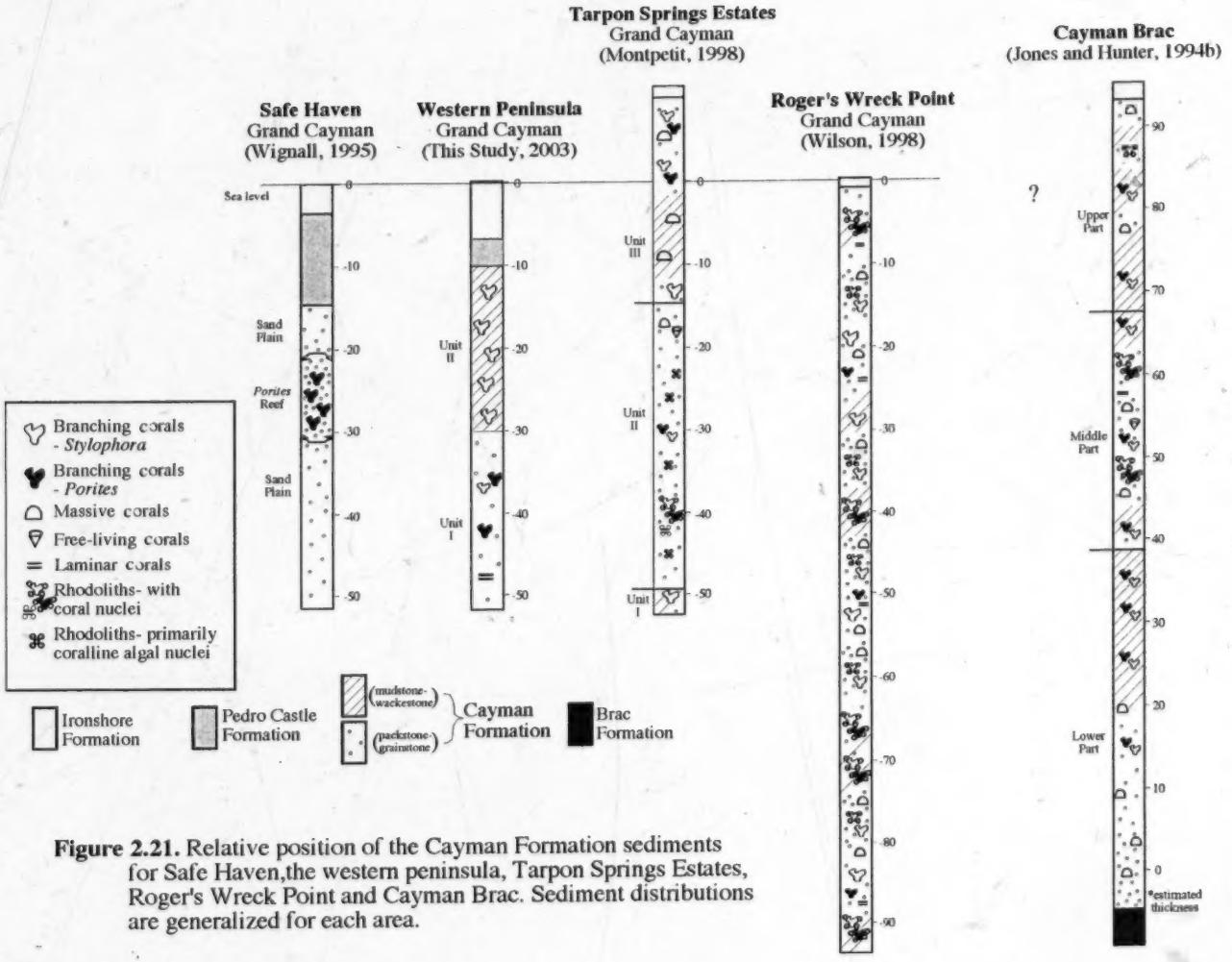


Figure 2.21. Relative position of the Cayman Formation sediments for Safe Haven,the western peninsula, Tarpon Springs Estates, Roger's Wreck Point and Cayman Brac. Sediment distributions are generalized for each area.

Safe Haven-western Grand Cayman

The (north-south) western transect of the study area overlaps, and shares a well (SH#3), with Wignall's (1995) east-west transect through the Safe Haven area. The study area is located to the east of most of the Safe Haven area.

Wignall (1995) delineated seven grainstone and packstone dominated facies in the Cayman Formation of the Safe Haven area, and organized them into four distinct depositional environments: sand plain, *Porites* reef, near reef, and storm. The sand plain depositional environment, characterized by three skeletal packstone/grainstone, minor wackestone facies dominates the Cayman Formation in the Safe Haven area (Wignall, 1995) (Figure 2.22).

The biota of the sand plain depositional environment includes coralline algae, *Amphistegina*, *Halimeda*, and molluscs (Wignall, 1995). Branching corals are rare. The facies of the sand plain depositional environment interfinger on a metre scale, but no large scale trends are apparent (Wignall, 1995). The facies of the sand plain depositional environment are very similar to this study's skeletal facies association, although they contain less mud, allochems may be more fragmented (mollusc fragments are well rounded in the mollusc-*Amphistegina-Halimeda* facies), and contain more *Halimeda* and molluscs fragments.

The *Porites* reef, and associated near reef (reef talus) environment, extends for at least one km in a north-south direction, possibly following a bathymetric trend, through the Safe Haven area (Wignall, 1995). The reef is approximately 300 m wide, and is located between 22 m and 32 m bsl. The greatest E-W lateral extent appears to have been stratigraphically located at ~22 m to 30 m bsl. It probably grew in 15-25 m of water in a sediment-stressed environment (Wignall, 1995). The *Porites* reef was not a fringing reef (Wignall, 1995). It was thought to have baffled shifting sands, but did not act as a major barrier to swell and current energies (Wignall, 1995). No reefs were found in this study, although the *Porites*-intraclast-rhodolith facies may have been storm derived talus from such a buildup. Storm influenced environments are more widespread in the study area than in the Safe Haven area.

The *Stylophora* facies association, which dominates the upper part of the Cayman Formation in the study area, was not reported from the Safe Haven area. A small

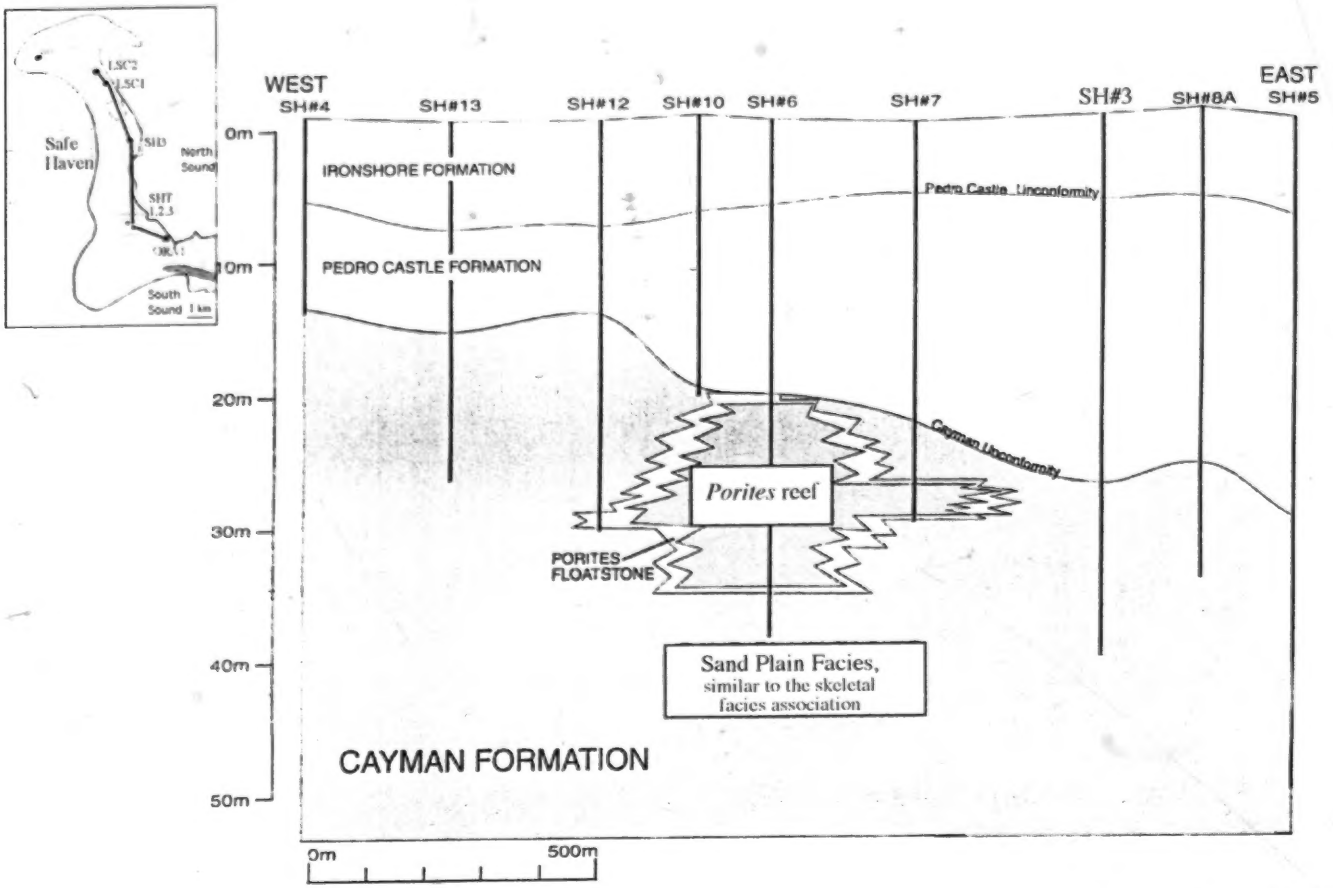


Figure 2.22. West- east cross section of the Safe Haven area showing the *Porites* reef (modified from Wignall, 1995). The Safe Haven area is centrally located on the western peninsula. The western transect also includes well SH#3.

interval of it is recorded by this study in SH#3, the shared well between the two studies, but it was included with the sand plain facies by Wignall (1995). The *Stylophora* facies association is characterized by wackestone to mudstone matrix textures that are rare in the Safe Haven area. Equivalents to the *Stylophora* facies association are described from the rest of the Grand Cayman (Montpetit, 1998; Wilson, 1998) and Cayman Brac (Hunter, 1994) study areas.

The Cayman Formation at Safe Haven was probably deposited above storm base on an open bank in 10-30 m of water, in an environment subject to high-energy levels and sedimentation rates (Wignall, 1995). Wignall (1995) suggested that the Safe Haven area was either preferentially sheltered from strong ocean currents during the Miocene, or that such currents did not exist around Grand Cayman at the time of deposition. This was based on the observation that sediment distribution appeared unaffected by currents. Thick sediment accumulations also led Wignall (1995) to suggest that the Safe Haven area was sheltered from cross-bank currents, or located in an area where sediment was preferentially trapped by antecedent topography or reef buildup.

Roger's Wreck Point- eastern Grand Cayman

Wilson (1998) examined the Cayman Formation in two wells from Roger's Wreck Point, northeast Grand Cayman, but found no evidence of reefal buildup, despite an abundance of framework-building fauna. *Stylophora* thickets were identified, but were considered too patchy to have significantly sheltered inner bank facies.

The carbonate succession at Roger's Wreck Point is characterized by repeated vertical stacking of five coral and rhodolith rich facies (Wilson, 1998). The Rhodolite Finger Coral Floatstone, the Rhodolite Coral Fragment Floatstone-Grainstone and the *Porites Leptoseris Montastrea Stylophora* Floatstone facies dominate the succession. The *Stylophora* Floatstone and *Leptoseris-Montastrea* Floatstone facies constitute scattered horizons. The facies were positioned on a bank edge to inner bank transect, primarily based on their respective energy levels (Wilson, 1998). Facies dominated by laminar corals were interpreted as representing high energy, low sedimentation end member environments, whereas facies dominated by branching corals represent low energy, high sedimentation end member environments (Wilson, 1998).

Wilson (1998) did not detect any systematic vertical or lateral trends in the Cayman Formation at Roger's Wreck Point, finding that continuous, but slight environmental fluctuations controlled deposition. Facies distribution reflects a biological response to repeated storm events, with relative water depth exerting only a minor influence (Wilson, 1998). Deposition was interpreted as taking place on an unprotected windward bank edge within storm wave base in 5-30 m of water (Wilson, 1998).

Tarpon Springs Estates- southern Grand Cayman

Montpetit (1998) examined the Cayman Formation in outcrop and three cores at Tarpon Spring Estates, located on the south central coast of Grand Cayman. He divided the Cayman Formation into three depositional units (I, II, III) of genetically related facies that were capped by hardgrounds. The lower units are at the same stratigraphic depth as the study area and the Safe Haven area. Material stratigraphically equivalent to unit III has been totally removed from the Safe Haven area, and mostly removed from the study area.

Units I and III are characterized by corals that grew in an environment similar to the Safe Haven sand plain. These units are composed of fragmented branching corals in coralline algal and foraminiferal packstone and wackestone sands (Montpetit, 1998). Corals are not in situ.

Unit II is characterized by thick deposits of rhodoliths, most commonly nucleated on coralline algal fragments, in skeletal packstone matrixes (Montpetit, 1998). Free living and massive corals are common towards the top of the unit. Unit II was interpreted as representing higher energy, shallower water conditions than units I or III, characterized by a low sedimentation rate and mobile sandy substrate (Montpetit, 1998). Units II and III are directly comparable to the middle and upper parts of the Cayman Formation on Cayman Brac in biotic composition and in thickness (Montpetit, 1998). Facies equivalent to unit II were not detected in either the Safe Haven area or the western transect.

No reefal buildups were found in the Cayman Formation at Tarpon Spring Estates (Montpetit, 1998). The lack of reefs at Tarpon Springs Estates was attributed to high-energy rapidly shifting substrates (Montpetit, 1998). The Tarpon Springs paleoenvironment was interpreted to be an unrimmed windward margin of an isolated

bank swept by cross-bank currents. Energy levels were moderate to high, with water depths of 10-35m (Montpetit, 1998).

Cayman Brac

The Cayman Formation on Cayman Brac, estimated to be 100 m thick, is exposed in outcrops that can extend more than 30 m asl (Jones and Hunter, 1994b). Mudstones and wackestones dominate, although beds and lenses of rudstones, packstones, and grainstones are locally common (Jones and Hunter, 1994b). The coral fauna is diverse, but there is no evidence of reefal buildup apart from isolated *Stylophora* thickets. Deposition was in water less than 30 m deep, possibly as shallow as 10-15 m bsl, on an open bank subject to varying energy levels (Jones and Hunter, 1994b). Systematic, stratigraphic or geographic variation in facies were not recognized, possibly indicating similar depositional conditions over the full area of the bank (Jones and Hunter, 1994b). The Cayman Formation is arbitrarily divided into lower, middle, and upper parts (Jones and Hunter, 1994b).

The lower part contains a fining upward succession of skeletal sands. Massive corals are common lower in the section and branching corals common towards the top (Jones and Hunter, 1994b). Bioclastic wackestones to packstones dominate the middle part of the formation, although isolated beds of grainstones and rudstones along with lenses and thin beds of rhodolith rudstone are common (Jones and Hunter, 1994b). Massive and free living corals are locally common, branching corals are common throughout. Wackestones and packstones with minor mudstones dominate the upper part of the formation. Branching corals are common in mudstones whereas massive corals are more common in the wackestones and packstones. Rhodoliths are less common than in the middle part of the formation. Wignall (1995) interpreted the Cayman Formation at Safe Haven to represent the upper part of the Cayman Formation on Cayman Brac.

The diversity of the coral fauna in the study area is relatively poor as compared to that of Cayman Brac (Jones and Hunter, 1994b), Tarpon Springs Estates (Montpetit, 1998), Roger's Wreck Point (Wilson, 1998), or Grand Cayman in general (Hunter, 1994). This may be due to the muddy consistency of the substrate. Jones and Hunter (1994b) suggested that the amount of mud in the water column and the condition of the substrate, rather than water depth or geographic position, determined the distribution of corals in

the Cayman Formation on Cayman Brac. They noted that branching corals were common in mudstone and wackestone facies, but rare in packstone and grainstone facies. In situ branching corals are very common in the mudstones and wackestones of the study area. Massive corals were common in the Cayman Brac packstone and grainstone facies, but rare in muddier facies; most likely a result of their inability to survive in areas where energy levels were insufficient to remove fine-grained sediment (Jones and Hunter, 1994b). Packstone textures in the study area, however, are either coral poor, or are dominated by fragmented branching corals. This may be partly due to high levels of predation (evidenced by pervasive boring casts in *Stylophora*) and periodic storm disturbance, conditions to which the fast growing ramose form of the branching coral is better suited. It may also reflect poor recruitment of the massive corals.

Summary

The Cayman Formation in the western transect area was deposited on the leeward side of an open bank subject to periodic storms. Water depth was < 30 m, and commonly < 20 m. Deposition took place under two distinct depositional regimes controlled primarily by relative water energy. The lower unit contains an assortment of facies and matrix textures that were deposited under dominantly moderate to high energy conditions with low sedimentation rates. Facies are not laterally extensive. The upper unit is composed exclusively of the *Stylophora* facies association. The upsection shift to depositional Unit II corresponds with an increase in mud content and a decrease in facies variability and coral diversity, most notably a reduction in *Porites baracoaensis*. Energy levels were low and sedimentation rates were high. Moderate energy incursions of the skeletal facies association happened repeatedly during deposition of the Cayman Formation.

Facies distribution in the Cayman Formation cannot be correlated between Grand Cayman or Cayman Brac study areas, although individual facies may be found in several locations. The Cayman Formation in the western transect area has an overall muddier texture and contains more branching corals and fewer rhodoliths and massive corals than other Grand Cayman and Cayman Brac study areas.

Chapter 3: Sedimentology and Facies Architecture of the Pedro Castle Formation

The Pedro Castle Formation unconformably overlies the Cayman Formation. The Cayman Unconformity, which is the basal boundary of this succession, developed during a Late Miocene low stand that may have lasted 1.5 million years (Jones and Hunter, 1994a; Wignall, 1995). The Cayman Unconformity is a karst surface characterized by an outer peripheral ridge that surrounded a large depression under what is now North Sound (Figure 3.1). The north and south sides of that ridge were broken by large gaps. The peripheral high on western Grand Cayman is lower and less continuous than on the southern, eastern, and northern coasts.

The unconformity has a topographic relief of at least 11.6 m in the study area (a relief of at least 36.9 m has been recorded for Grand Cayman (Jones et al., 1994), forming a N-S bowl-shaped depression (Figure 3.2). The Pedro Castle Formation filled topographic lows on top of the Cayman Unconformity, with much of it later being removed by late Pliocene- early Pleistocene erosion (Arts, 2000). The original thickness of the Pedro Castle Formation may have been greater than 44 m (Arts, 2000); however, the thickest section in the study area is just over 21 m. The Pedro Castle Formation has been entirely removed from the southern most well in the area and limited sections remain in the SHT wells.

Recovery is commonly poor at the base of the Pedro Castle Formation, whereas recovery is good at the top of the underlying Cayman Formation due to case hardening. This difference in recovery has been used to estimate the location of the formation contact during drilling (Jones et al., 1994, Wignall, 1995). The Pedro Castle Formation is white in lower sections, but commonly becomes tinted bluish-grey or tan up section. This is a calcretization texture, common in the upper 3-4 m of the Pedro Castle Formation (Wignall, 1995).

The Pedro Castle Formation is partially dolomitized. Mineralogic composition varies from dolostone to calcitic dolomite and dolomitic limestone to limestone. Mineralogy does not appear to be tied to facies type, however, dolomitization does

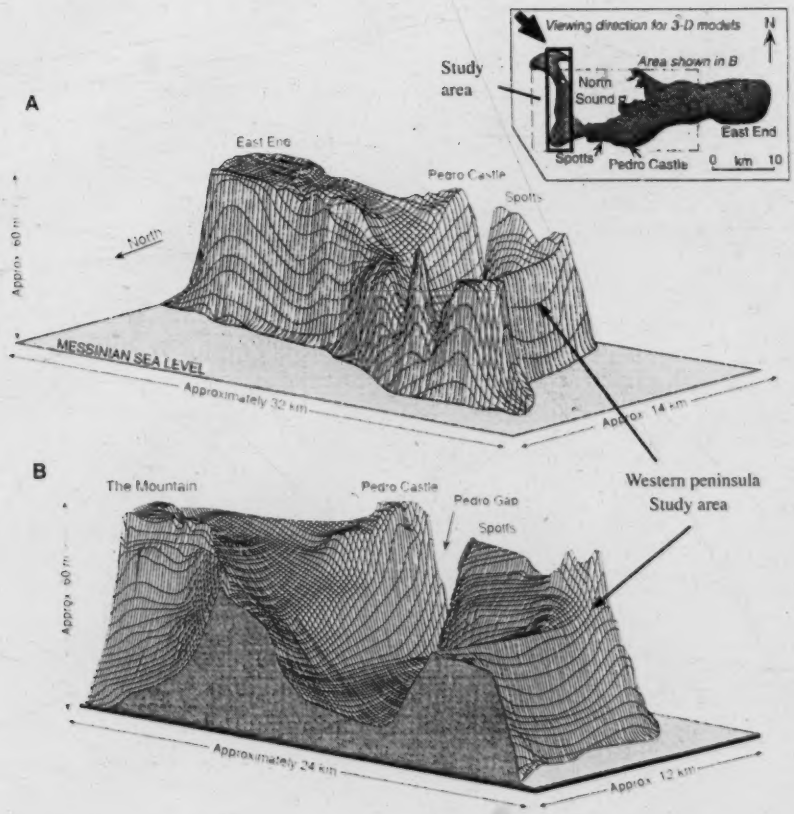


Figure 3.1. The Cayman Unconformity surface as depicted by Jones and Hunter, 1994a. Note that the elevation of the western peninsula is lower than that of the southern and eastern peripheral highs.

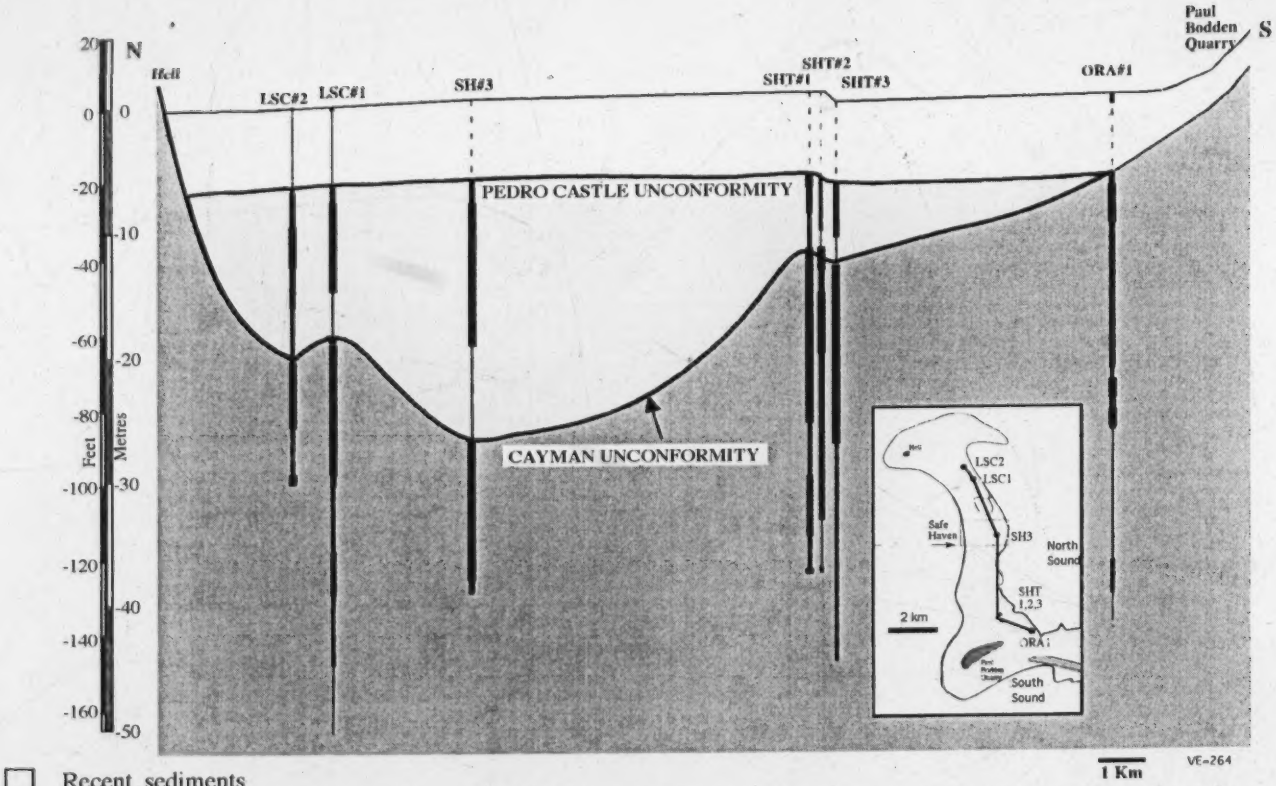


Figure 3.2. Distribution of the Cayman, Pedro Castle and Ironshore formations along a N-S cross section through Grand Cayman's western peninsula. Paul Bodden Quarry and Hell are field exposures examined by Jones et al., 1994. The width of the well represents relative core recovery; a dashed line indicates no recovery.

consistently decrease upsection (Appendix A). Secondary calcite cements are pervasive. The base of the Pedro Castle Formation can be difficult to differentiate from the underlying Cayman Formation. Although the Cayman Formation is exclusively dolostone, calcite cements at the top of the Cayman Formation and a dolomitic composition at the base of the Pedro Castle Formation may preclude easy differentiation by mineralogy in core. In the study area, the Pedro Castle Formation can be distinguished from the Cayman Formation by a less muddy texture (dominantly packstone versus wackestone) and the presence of numerous forams, rhodoliths and free-living solitary corals (Figure 3.3).

Skeletal Components and Preservation

The allochem content of the Pedro Castle Formation is similar to that of the Cayman Formation. The diversity, however, of the commonly occurring fauna is greater (Figure 3.3). This may be related to less extreme diagenetic alteration in the Pedro Castle Formation as compared to the Cayman Formation (Wignall, 1995). The increased diversity, however, is most evident in corals and benthic foraminifera, fauna that were generally easy to identify in the Cayman Formation due to distinctive molds or well preserved tests. This suggests that increased diversity in the Pedro Castle Formation is a true reflection of increased faunal diversity during the time when the Pedro Castle Formation was being deposited (Wignall, 1995).

The core from the lower part of the Pedro Castle Formation has been better preserved than the Cayman Formation core. Dololmitization can be fabric retentive or fabric destructive, and is commonly fabric selective. Preferential dolomitization of mud fill in coralline algae, *Halimeda*, and boring and bioturbation structures (Figures 3.4, 3.5, 3.6) results in excellent fabric definition. The top of the Pedro Castle Formation, however, has been subject to severe diagenetic alteration that commonly obscures allochems and depositional fabrics. Severe overprinting may preclude facies identification.

Large allochems (>2 mm), most commonly rhodoliths and free-living solitary corals, are less common in the Pedro Castle Formation than in the Cayman Formation. The dominant Pedro Castle Formation matrix allochems (<2mm) are foraminifera.

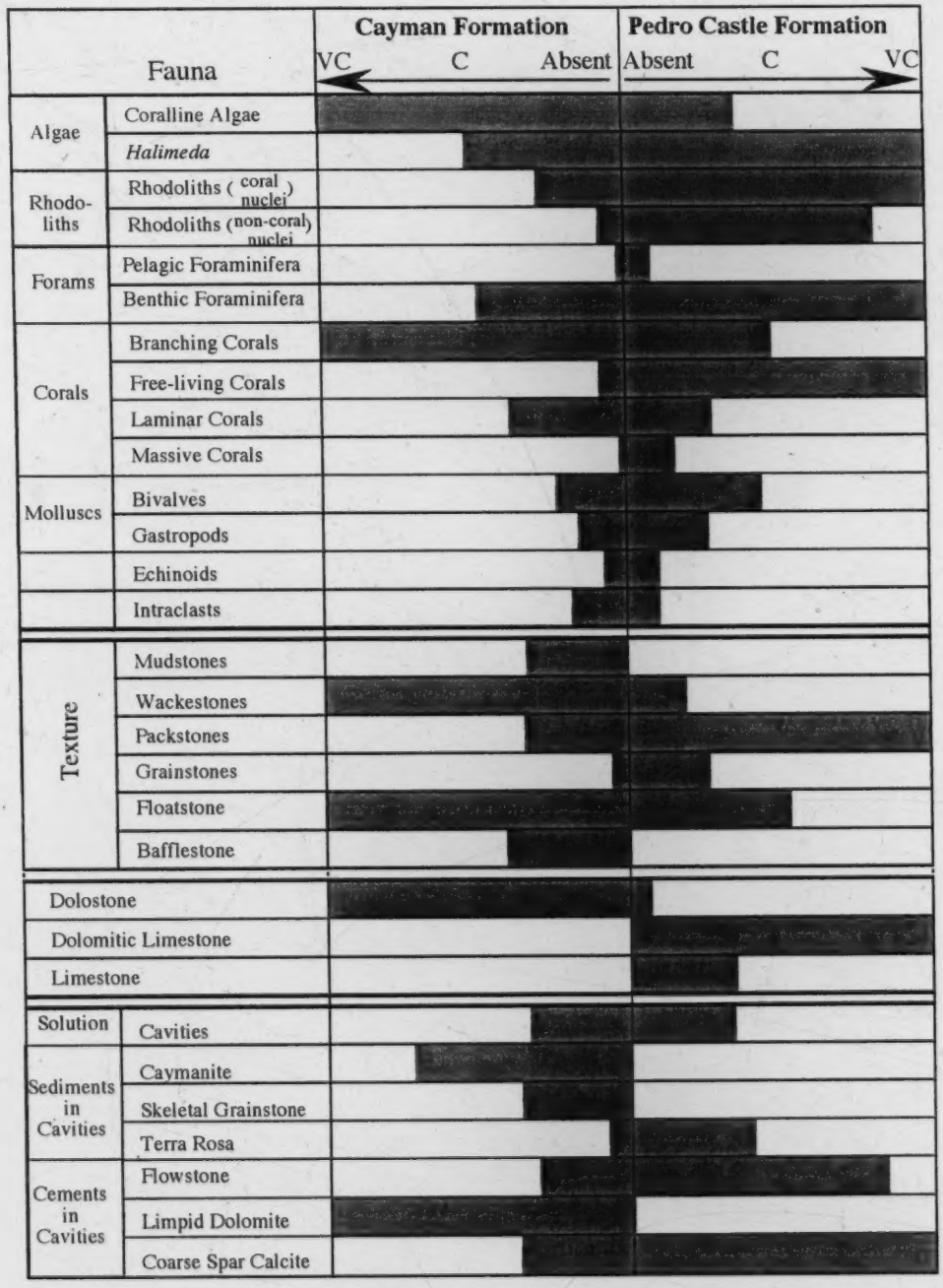


Figure 3.3 Comparison of characteristics of the Cayman and Pedro Castle formations. Attributes are generallized based on all of the examined core for each formation in the study area.

Figure 3.4. Coralline algae preservation. Calcite is stained pink; dolomite appears greenish. A,B, C) Mud infill in the coralline algae cells is preferentially dolomitized. D) Fabric destructive dolomitization.

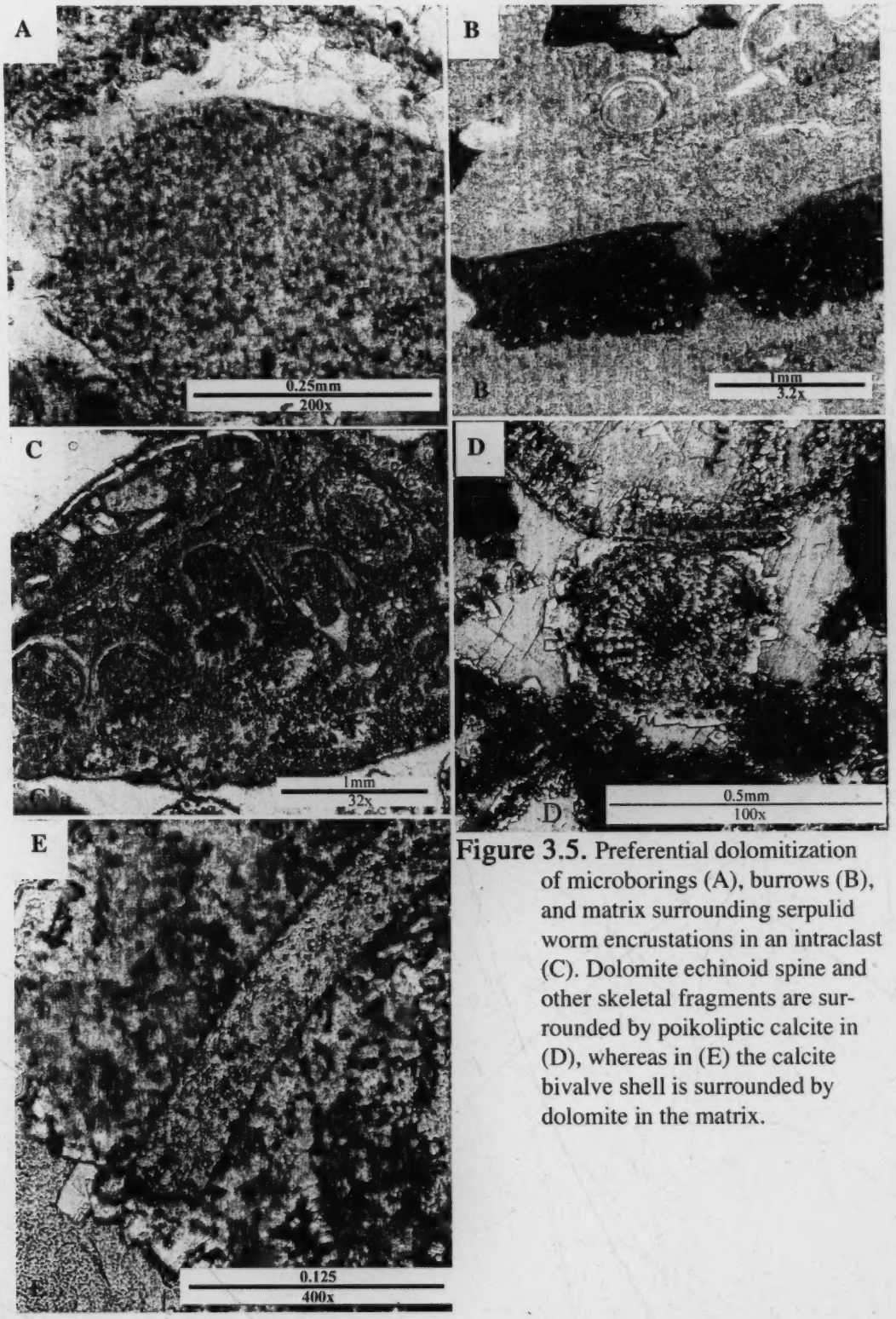


Figure 3.5. Preferential dolomitization of microborings (A), burrows (B), and matrix surrounding serpulid worm encrustations in an intraclast (C). Dolomite echinoid spine and other skeletal fragments are surrounded by poikoliptic calcite in (D), whereas in (E) the calcite bivalve shell is surrounded by dolomite in the matrix.

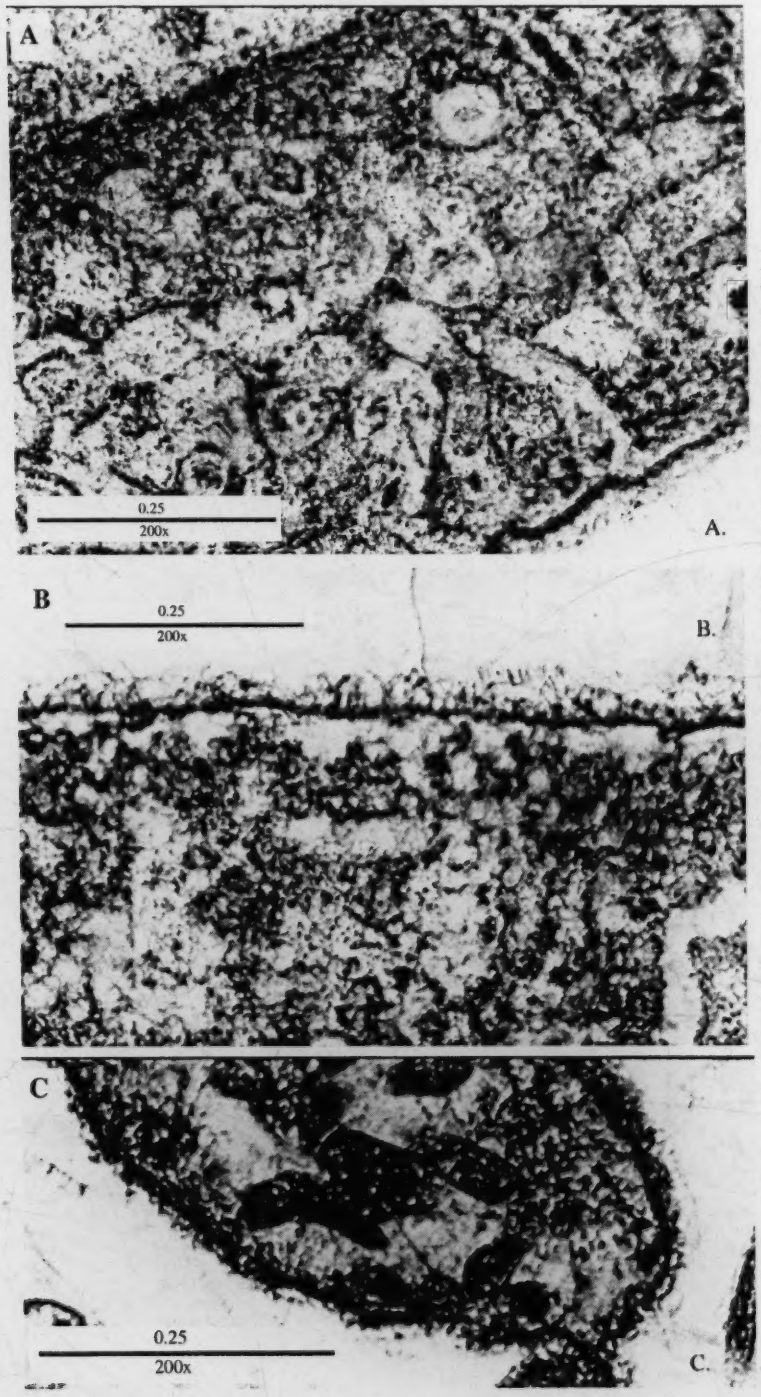


Figure 3.6. Different styles of *Halimeda* preservation. In (A) the tubules are calcite and the plate is preferentially dolomitized. In (B) the calcite tubules are not distinct, and poikoliptic calcite has surrounded the dolomite in the plate. In (C) the tubules have been preferentially dolomitized and the plate is calcite.

Rhodoliths vary in size from < 1 cm to > 5 cm across. The shape of small rhodoliths reflects the type of nuclei; small rhodoliths nucleated on branching corals are commonly prolate in shape, whereas small rhodoliths nucleated on skeletal fragments or intraclasts are commonly spherical. Larger rhodoliths are spherical in shape regardless of nucleus material. The rhodolith cortex can be up to 2 cm thick. The cortex is composed primarily of crustose coralline algae (possibly *Lithophyllum* and *Neogeolithon*) and minor encrusting forams (*Carpenteria*) in a nodular to concentric morphology. Diagenetic overprint commonly stains rhodoliths a darker bluish grey than the surrounding matrix.

Trachyphyllia bilobata is the most common free-living coral; *Trachyphyllia* n. sp., *Thysanus* and *Teleiophylla* are less common. They have been leached so that a negative mold remains. Boring casts are common. Little fragmentation is apparent from the negative molds. Branching corals are common in the Pedro Castle Formation, but not abundant. They are most commonly severely fragmented and encrusted by coralline algae, and as such are classified as rhodoliths. Massive and laminar corals are relatively rare, although massive corals are more common than in the Cayman Formation.

Amphistegina and *Sphaerogypsina* are the dominant foraminifera; miliolids, soritids and encrusting forams (*Carpenteria*) are common. Encrusting foraminifera are most common in Rhodoliths or encrusting other foraminifera, but may also be unattached. Large *Sphaerogypsina* and *Amphistegina* can be > 2 mm in diameter (Figure 3.8). Pelagic foraminifera are more common than in the Cayman Formation, but usually make up < 5% of the total foram content. Foraminifera are well preserved (Figure 3.7); total dissolution is rare. Fragmentation is common, and is especially apparent in the soritids. More robust *Amphisteginids* and *Sphaerogypsina* commonly show minor breakage. Easily fragmented foraminifera may be underrepresented.

Halimeda and mollusks are more common than in the Cayman Formation. *Halimeda* is recognizable in core as well preserved plates or hollow molds that may be filled with calcite spar. Bivalves and gastropods are commonly leached, the molds filled with calcite spar. Large crustose coralline algae and echinoid fragments each account for ~5% of the total allochems. Coralline algae are commonly well preserved, only rare specimens have been subject to dissolution. Cement overgrowths are common on the echinoid fragments.

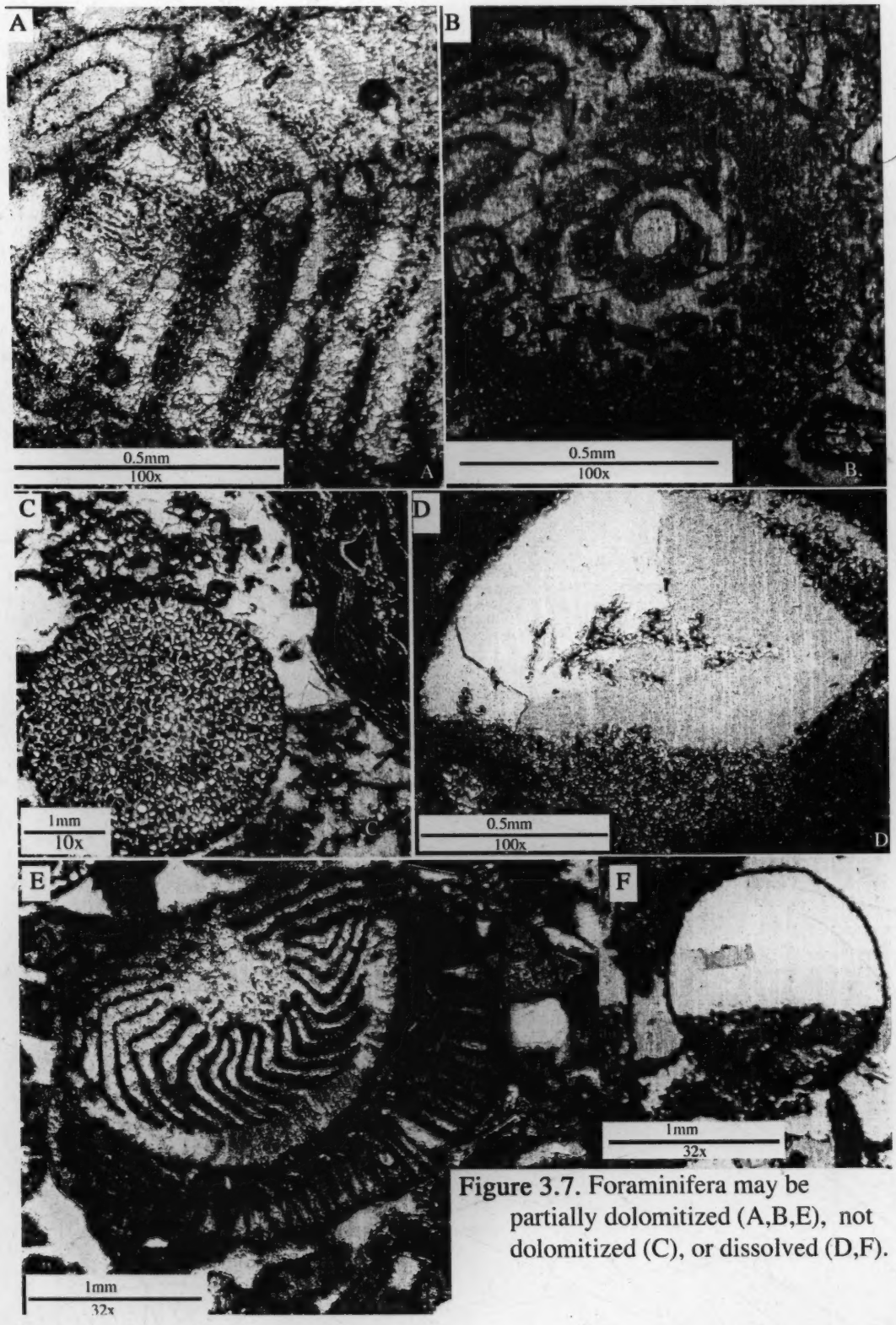


Figure 3.7. Foraminifera may be partially dolomitized (A,B,E), not dolomitized (C), or dissolved (D,F).

LSC#2- 7.3m from top of core

Figure 3.8

SHT#3- 11m from top of core

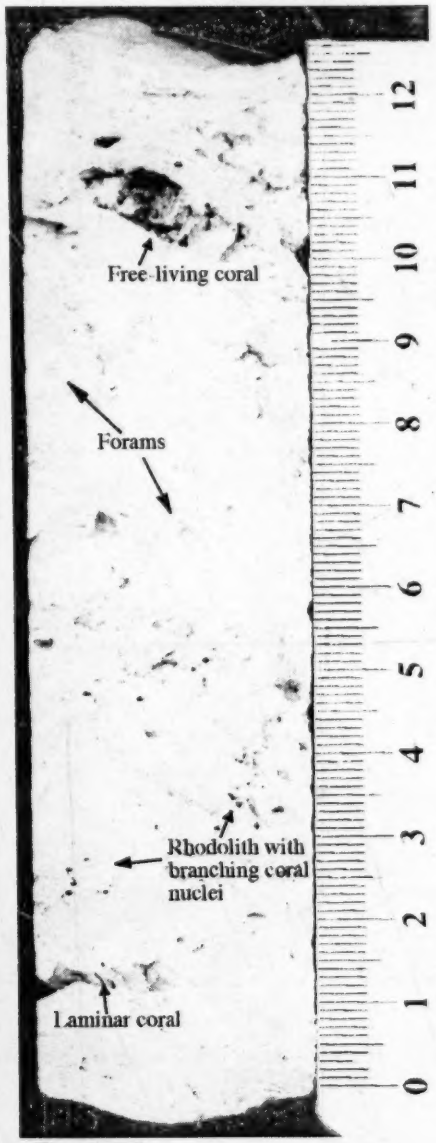


Figure 3.9

Pedro Castle Formation

Figure 3.8. Scanned core of the rhodolith-foram facies. Pink hue is from smeared terra rosa.

Figure 3.9. Diagenetic overprinting of rhodoliths has stained them a darker grey than the matrix.

Facies of the Pedro Castle Formation and their Interpretation

Seven facies were delineated in the Pedro Castle Formation (Table 3.1). Physical structures were not observed. Facies boundaries are commonly gradational.

Coral distribution has been compared with that of the coral associations described by Hunter (1994) where applicable. Facies and their distribution are very similar to those from other western Grand Cayman study sites. Facies from the Pedro Castle Formation on Cayman Brac are dissimilar in terms of facies characteristics (due to a much higher percentage of red algae and fewer forams (MacNeil, 2000) and distribution and are not discussed.

Rhodolith- Foraminifera Facies

Description

This common facies is characterized by rhodoliths in a foraminifera wackestone to packstone matrix (Figure 3.8, 3.9). Free-living corals are sparsely distributed throughout the facies. *Halimeda* is locally very common, and common throughout. *Amphistegina* and *Sphaerogypsina* are dominant foraminifera; miliolids and soritids are common, globorotalids are rare. *Carpenteria* is common in the rhodoliths.

The size of the rhodoliths is variable, and may be up to 5 cm in diameter. Rhodoliths nucleated on coral fragments have partially dissolved cores. Branching corals and skeletal fragments are the most common rhodolith nuclei, but intraclasts, free-living corals and laminar corals also served as nuclei for the coralline algae. Rhodoliths of similar size are grouped together, but no pattern of gradation is recognized. Rhodolith distribution is uneven; they can be tightly grouped, comprising ~40% of the core volume, or sparsely distributed, accounting for ~10% of the core volume.

Free-living corals form 3-10% of the core volume and are unevenly distributed. Laminar corals, massive corals, and unencrusted branching corals are rare. Echinoids, bivalves, and coralline algae are minor matrix components. Skeletal fragments are common. Matrix allochems are fine to coarse grained, fragmented, and commonly micritized.

Facies	Facies Description	Major Allochems	Minor Allochems	Non-Skeletal	Comments	Similar to:	Environment
Rhodolith-Foraminifera (RhF)	Rhodolith Floatstone with foraminifera dense **Wackestone to Packstone** matrix, rare **Grainstone**	*Amphistegina, Sphaerogypsina,* rhodoliths, *Halimeda, Trachyphyllia*	soritids, miliolids, *Carpentria,* bivalves, gastropods, coralline algae, echinoids, *Leptoseris , Porites, Stylophora,* globorotalids, green algae	(<1cm->5cm) rhodoliths-abundant intraclasts-rare	Same sized rhodoliths are grouped together; no overall pattern of distribution is recognized.	Wignall (1995)- Rhodolith-Foraminifera- *Halimeda* Pack-Grainstone Arts (2000)- Rhodolith-*Amphistegina -Trachyphyllia* Wackestone Hunter (1994)- Free-living Coral Association	High Energy Unconformity Colonization/ Unrestricted Lagoon
Trachyphyllia-Foraminifera-*Halimeda (TFH)*	*Trachyphyllia* Floatstone with foraminifera-*Halimeda* **Packstone** matrix, **local Grainstones**	*Amphistegina, Trachyphyllia, Halimeda*	soritids, miliolids, *Teleiophylla,* Sphaerogypsina, bivalves, gastropods, echinoids, coralline algae, *Thysanus, Stylophora, Montastrea, Carpentria*	small rhodoliths-rare	Laterally restricted uncommon facies.	Wignall (1995)- Solitary Coral-Foraminifera- *Halimeda* Wackestone Packstone	High Energy Unrestricted Lagoon
Foraminifera (F)	Foraminifera- skeletal fragment dense **Wackestone** to **Packstone, local Grainstone**	*Amphistegina, Sphaerogypsina*	soritids, miliolids, bivalves, *Halimeda,* coralline algae, echinoids, *globorotalids,* gastropods, *Trachyphyllia, Montastrea*	small rhodoliths	Limited diversity and abundance of biota.	Wignall (1995)- Foramin-ifera-Mollusc Packstone Arts (2000) Amphistegina-Rhodolith facies Packstone, local Grainstones Arts (2000) Bivalve-Foram-Halimeda-Rhodolith pack-wackestone, local grainstone	Fluctuating Energy Conditions-Restricted Lagoon
Foraminifera-Halimeda- Bivalve (FHB)	Foraminifera- *Halimeda*-bivalve **Packstone, local Wackestones** and **Grainstones**	Amphistegina, Sphaerogypsina, *Halimeda* , bivalves	soritids, miliolids, gastropods, *Carpentria* , echinoids, globorotalids, *Stylophora*	small rhodoliths-rare	Bivalves can be robust, with several mm thick shells.	Wignall (1995)- *Halimeda,* Mollusc Wackestone to Packstone	Moderate Energy Restricted Lagoon

Foraminifera-Mollusc-*Halimeda* (FMH)	Foraminifera- Mollusc-*Halimeda* **Wackestone** to **Packstone**	*Amphistegina* , *Sphaerogypsina* , bivalves, *Halimeda* , gastropods	soritids, miliolids, echinoids, *Styplophora, Montastrea, Trachypyllia,* globorotalids, *Leptoseris*	small-medium rhodoliths	Bivalves can be robust, with several mm thick shells.	Wignall (1995)-Mollusc, *Halimeda,* Foraminifera Wackestone to Packstone Arts (2000)-*Stylophora -Halimeda - Amphistegina* Wackestone to Packstone	Moderate Energy Restricted Lagoon
Foraminifera-*Halimeda (FH)*	Foraminifera- *Halimeda* **Packstone**	*Amphistegina, Sphaerogypsina, Halimeda,* soritids, miliolids	bivalves, gastropods, *globorotalids,* coralline algae, echinoids	small rhodoliths (<1 cm), small intraclasts-rare	Abundant *Halimeda* easily identifiable in core.	Arts (2000)- *Halimeda-Amphistegina* Wackestone to Mudstone	Moderate Energy Restricted Lagoon
Stylophora - Amphistegina (StF)	Stylophora Floatstone with *Amphistegina* **Wackestone** matrix	*Stylophora, Amphistegina*	*Halimeda,* bivalves, Porites, gastropods, soritids, miliolids, echinoids, coralline algae	small -medium rhodoliths	Uncommon facies, heavy diagenetic overprinting.	Wignall (1995)-*Stylophora,* Mollusc, Foraminifera Wackestone to Packstone Arts (2000)- *Stylophora-Halimeda-Amphistegina* Wackestone to Packstone	Low Energy Unrestricted Lagoon

Figure 3.1. Facies of the Pedro Castle Formation for the n-s western transect study area

Interpretation

Rhodoliths, the dominantly packstone matrix, abundant *Amphistegina*, and the free-living corals all indicate high-energy conditions. The nodular to concentric rhodoliths require frequent overturning by at least moderate wave energy to attain even, concentric algal growth (Scoffin et al., 1985; Boscence, 1991). Energy levels, however, were not as high as those of typical open water, as too much energy is damaging to the delicate algae thallus (Hills, 1998). The cortex is thicker than the cortex of the Cayman Formation rhodoliths. This may be due to sheltering from storms that would have periodically removed rhodolith populations (Hills, 1998). This is based on observations by Martindale (1992) that, in Barbados, thicker rhodolith cortexes indicate proportionally longer periods of time in the environment before burial. Fragmented branching coral nuclei suggests high-energy shallow water conditions less than 30 m deep (Jones and Hunter, 1994).

Trachyphyllia bilobata, the most common coral in this facies, had a bathymetric range of 5-40 m bsl (Hunter, 1994). Hunter's (1994) Free Living Coral association, which is characterized by sparse free living corals (<10% of the sediment volume) in a sandy matrix of forams, *Halimeda*, rhodoliths, molluscs and rare red algae and colonial corals, is similar to the foraminifera-rhodolith facies. The free-living corals were interpreted to have grown as isolated colonies on a shallow water bank 10-20 m bsl, possibly as deep as 30 m bsl, in a moderate to high energy environment (Hunter, 1994).

The benthic foraminifera assemblage, large size of the foraminifera, and paucity of delicate pelagic foraminifera also indicates high-energy shallow waters < 30 m deep. Up to 30% of the sand in modern lagoons and open shelves around Grand Cayman is made up of foraminifera tests (Li, 1997). Soritids and miolinids suggest a sheltered lagoonal or bank setting (Wright and Murray, 1972; Moussa et al, 1987; Venec-Peyre, 1991; Wignall, 1995); however, amphisteginids are most commonly described from forereef settings (Seiglie and Moussa, 1981; Venec-Peyre, 1991; Li, 1997). The mixed assemblage may be due to amphisteginids preferential colonization of hard substrates (Poag and Tresslar, 1981; Li, 1997), and/or postmortem transport (Wignall, 1995). The loose sediments above normal wave base would have been subject to sorting, transportation, and mixing (Li, 1997).

Trachyphyllia- Foraminifera- *Halimeda* Facies

Description

Free-living solitary corals are very common in this relatively rare facies (Figure 3.10). They are unevenly distributed, and make up between 10% and 30% of the core volume. Fragmentation is rare. *Trachyphyllia bilobata* is the most abundant, *Trachyphyllia* n. sp. (Hunter, 1994), and *Teleiophylla* are less common. *Thysanus* is rare. Coral size varies from 2 cm to more than 6 cm in diameter. Massive corals are common, and branching corals are rare.

The corals are floating in a foraminifera-*Halimeda* packstone matrix, with local grainstones. Amphisteginids are the most common foraminfera, soritids and miliolids the next most abundant, whereas *Sphaerogypsina* is relatively rare. *Sphaerogypsina* can be as large as 3 mm in diameter. Large bivalves, coralline algae, and echinoids are minor components. Matrix allochems range from medium coarse to coarse grained, and may be heavily fragmented.

Interpretation

The low levels of abrasion and growth position orientation indicate that the free-living corals are in situ. By Late Miocene, large solitary hermatypic corals inhabited reef-crest and lagoonal environments (Frost, 1977a). The immobile cup shape responded to rapid sedimentation by upward growth (Hunter, 1994), allowing the corals to live in silty and sandy substrates. The high number of corals indicates favourable environmental conditions, possibly in well circulated water between 10-20 m deep. The mud poor texture and coarse grain size indicates moderate to high energy conditions to which the corals were well adapted (Hunter, 1994).

Foraminifera Facies

Description

This facies is recognized by the sparseness of all allochems except foraminifera. Small rhodoliths (skeletal nuclei), *Halimeda*, bivalves, echinoids, and free-living corals are minor components, rarely forming more than 10% of the allochems. *Amphistegina* and *Sphareogypsina* are the dominant foraminifera, soritids and miliolids are less

SH#3- 15.8m from top of core

Pedro Castle Formation

Figure 3.10. *Trachyphyllia*-foraminifera- *Halimeda* facies.

common, and pelagic foraminifera form 3-10% of the total foram content. Encrusting foraminifera are common in the rhodoliths. *Amphistegina* and *Sphaerogypsina* show minor fragmentation, other foraminifera and allochems are heavily fragmented. Matrix varies from dense wackestone to grainstone. Grain size is variable.

Interpretation

The limited biota and abundance of a single allochem are suggestive of a stressed environment. There is not a notable increase in soritids and miliolids that would clearly indicate restricted conditions, however these foraminifera may be underrepresented due to heavy fragmentation. Robust amphisteginids are abrasion resistant and may have been washed into the area of deposition after death (Li, 1997). The small size and limited number of rhodoliths may reflect a lack of large or suitable nuclei material, or conditions unsuitable for prolonged algal growth. Variable mud content and grain size indicates fluctuating energy conditions. These factors in combination suggest that this is a storm deposit dominated by abrasion resistant fauna. Conditions during fair weather may have been restrictive.

Foraminifera- *Halimeda*- Bivalve Facies

Description

This facies is characterized by foraminifera, *Halimeda*, bivalve packstones, with minor wackestones and grainstones. The relative allochem abundance is foraminifera > *Halimeda*> bivalves. Bivalves are commonly small and disarticulated, although rare specimens are up to 2 mm thick and up to 3 cm long. Gastropods form <10% of the total allochems. Mollusks are more recognizable in core, dissolved and filled with calcite than in thin section. Coralline algae and echinoids are minor components. Allochems are medium to coarse-grained, fragmented and may be micritized.

Large allochems are relatively rare. Free-living corals form < 5% of the core volume, branching and massive corals an even smaller percent. Rhodoliths are rare.

Interpretation

There is increased biodiversity as compared to the foraminifera facies, although *Halimeda*, bivalves, and gastropods are all tolerant of restricted conditions (Jones and

Desrochers, 1992). The high number of foraminifera is consistent with the foraminifera content in modern lagoons and open shelves around Grand Cayman (Li, 1997). The dominance of *Amphistegina* and *Sphaerogypsina* indicates moderate energy levels that may have destroyed less robust forms. Abundant *Halimeda* suggests a lagoonal environment as *Halimeda* may constitute up to 50% of the bottom sediments in subtropical lagoons (Wray, 1977). Thick shelled mollusks are thought to live in areas of higher water turbulence then less robust mollusks (Scoffin, 1987). The dominant packstone matrix texture, fragmentation of allochems, and medium to coarse grain size all indicate moderate energy levels.

Foraminifera- Mollusc- *Halimeda* Facies

Description

A greater number of robust and small bivalves and gastropods differentiate this facies from the foraminifera-*Halimeda* -bivalve facies (Figure 3.11). The matrix texture varies from a wackestone to a packstone, and allochems can be fine to very coarse in grain size. Sediments are less well sorted than in other facies. *Halimeda* forms 10-20% of the allochems. Foraminifera, dominated by *Amphistegina* and *Sphaerogypsina* in varying amounts, are the most common allochems. Pelagic foraminifera form 3-30% of the total foraminifera. Miliolids and soritids form <10% of the total foraminifera. Fragments of branching coral, rhodoliths with skeletal nuclei, and massive and free-living corals are rare.

Interpretation

The muddier texture and decreased sorting indicate lower energy conditions than the foraminifera-*Halimeda*-bivalve facies. A decrease in miliolids and soritids and an increase in delicate pelagic foraminifera indicate less restricted to unrestricted waters with a connection to open seas (Gill and Hubbard, 1985). Water depth has increased relative to that of the Foraminifera-*Halimeda*-bivalve facies.

LSC#2- 12.2m from top of core

Figure 3.11

SH#3- 7.9m from top of core

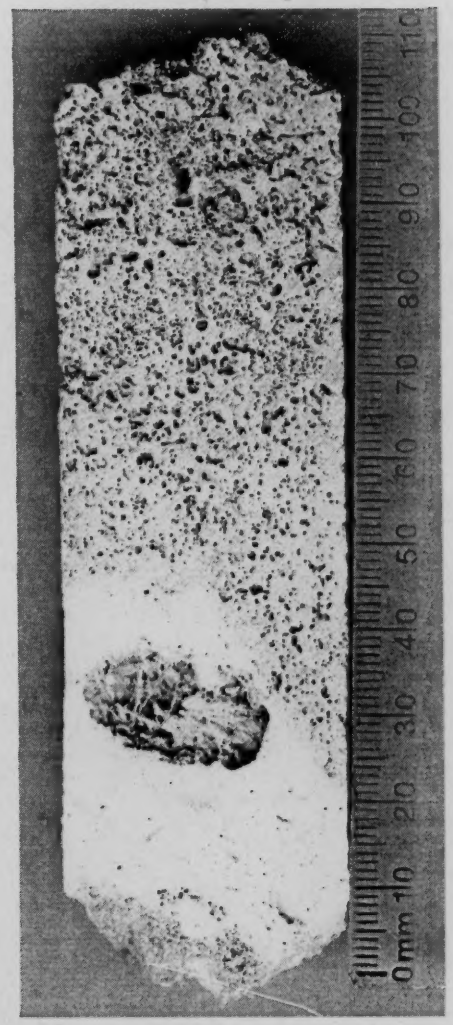


Figure 3.12

Pedro Castle Formation

Figure 3.11. Scanned core of the Foraminifera- mollusc- *Halimeda* facies.
Figure 3.12. Scanned core of the *Stylophora-Amphistegina* facies.

Foraminifera- *Halimeda* Facies

Description

This facies is similar to the foraminifera-*Halimeda*-bivalve and foraminifera-mollusk-*Halimeda* facies, but contains fewer molluscs. *Amphistegina* and *Sphaerogypsina* are the most common foraminifera; soritids and miliolids are slightly less abundant. Pelagic foraminifera form 1-5% of the total number of foraminifera. *Halimeda* constitutes 10- 30% of the allochem content. Intraclasts, rhodoliths, free-living corals, coralline algae, and echinoids are minor components. Grain size is medium coarse, fragmentation is minor, and micritization is light. The allochems are held in a packstone matrix.

Interpretation

The abundance of *Halimeda* and soritid and miliolid foraminifera indicates a restricted lagoonal environment. The coarse grain size, packstone texture, and minor fragmentation indicate a moderate energy environment.

Water depths are difficult to determine for this facies, as well as the foraminifera, foraminifera-*Halimeda*-bivalve, and foraminifera-mollusk-*Halimeda* facies due to a lack of framework corals and diagnostic fossil indicators. Deposition above normal wave base (~20-30 m) is suggested by abundant *Amphistegina* in sediments that otherwise are indicative of restricted environments. Deposition in the photic zone (generally above 80 m water depth) is indicated by the abundance of large foraminifera and *Halimeda*.

***Stylophora-Amphistegina* Facies**

Description

This facies, which has a restricted distribution, is located near the top of the formation (in the study area) and heavily overprinted by diagenesis (Figure 3.12). Large *Stylophora* fragments are common, whereas they are relatively rare in all other facies unless they have served as the nuclei for rhodoliths. They form ~10% of the facies. *Porites* fragments are less common. Small amphisteginids, scattered bivalves, *Halimeda*, and rare rhodoliths are held in the wackestone matrix.

Interpretation

The muddy textures and small grain sizes indicate low to moderate energy levels. This facies is similar to the *Stylophora* facies association in the Cayman Formation, but with fewer and more fragmented branching corals. This suggests that this facies may be have been deposited under less optimal, possibly deeper water (closer to 30 m bsl) conditions. Foraminifera are also more common and coralline algae less common than in the Cayman Formation *Stylophora* facies. *Amphistegina* is the only foraminifera genus found, which may indicate unrestricted conditions (Moussa et al., 1987).

Facies Architecture

The facies in the Pedro Castle Formation have greater lateral continuity and a more defined succession than the facies of the Cayman Formation (Figures 3.13, 3.14). Facies can be correlated between this study area, the Safe Haven area (Wignall, 1995), and the Lower Valley and Patrick Island Lagoon Transects (Arts, 2000) of western Grand Cayman, reoccurring in the same general sequence. The oldest facies drape the unconformity surface; younger facies gradually fill in the topography. Short, shallow sections of the Pedro Castle Formation do not contain a full succession of facies. North-south variations in facies distribution is not apparent, but is difficult to detect due to limited sections of the Pedro Castle Formation in southern wells.

The rhodolith-foraminifera facies consistently overlies the Cayman Unconformity, regardless of its position relative to sea level. This facies, and its position directly above the Cayman Unconformity, has been found throughout the western half of Grand Cayman (Wignall, 1995; Arts 2000). The thickness of the facies is variable, and can be up to 6.5 m thick. The rhodolith-foraminifera facies is the only facies in the stratigraphically shallow SHT#1 and SHT#3 wells (Figure 3.15, 3.16).

The rhodolith-foraminifera facies is overlain by the foraminifera facies in wells SH#3, SHT#2, LSC#1 and LSC#2. The foraminifera facies is similar to the *Amphistegina*-rhodolith facies in the Lower Valley area (Arts, 2000), and the foraminifera-mollusc facies in the Safe Haven area (Wignall, 1995). The foraminifera facies of this study, the *Amphistegina*-rhodolith facies of the Lower Valley area and the foraminifera-mollusk facies of the Safe Haven area are all stratigraphically low in the

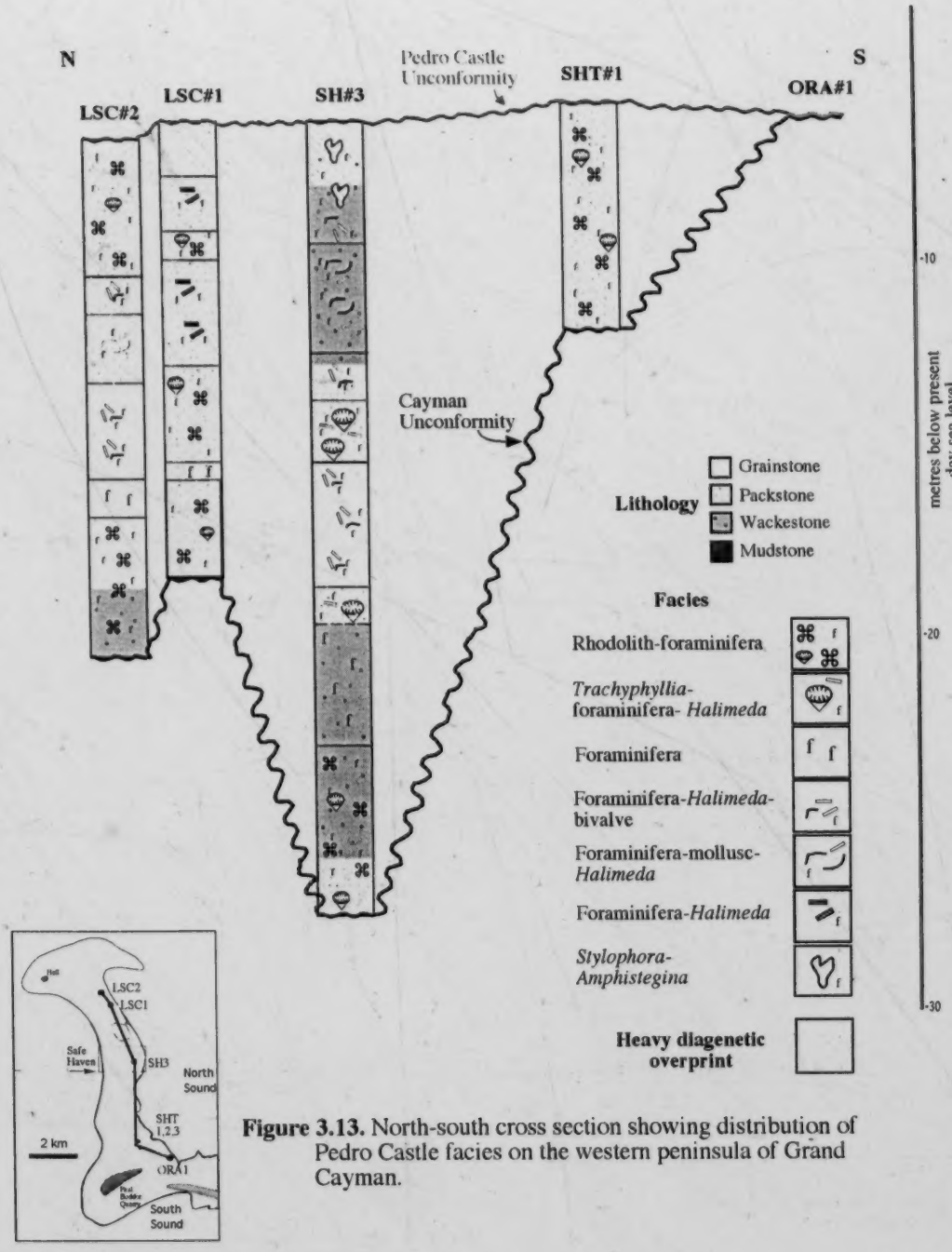
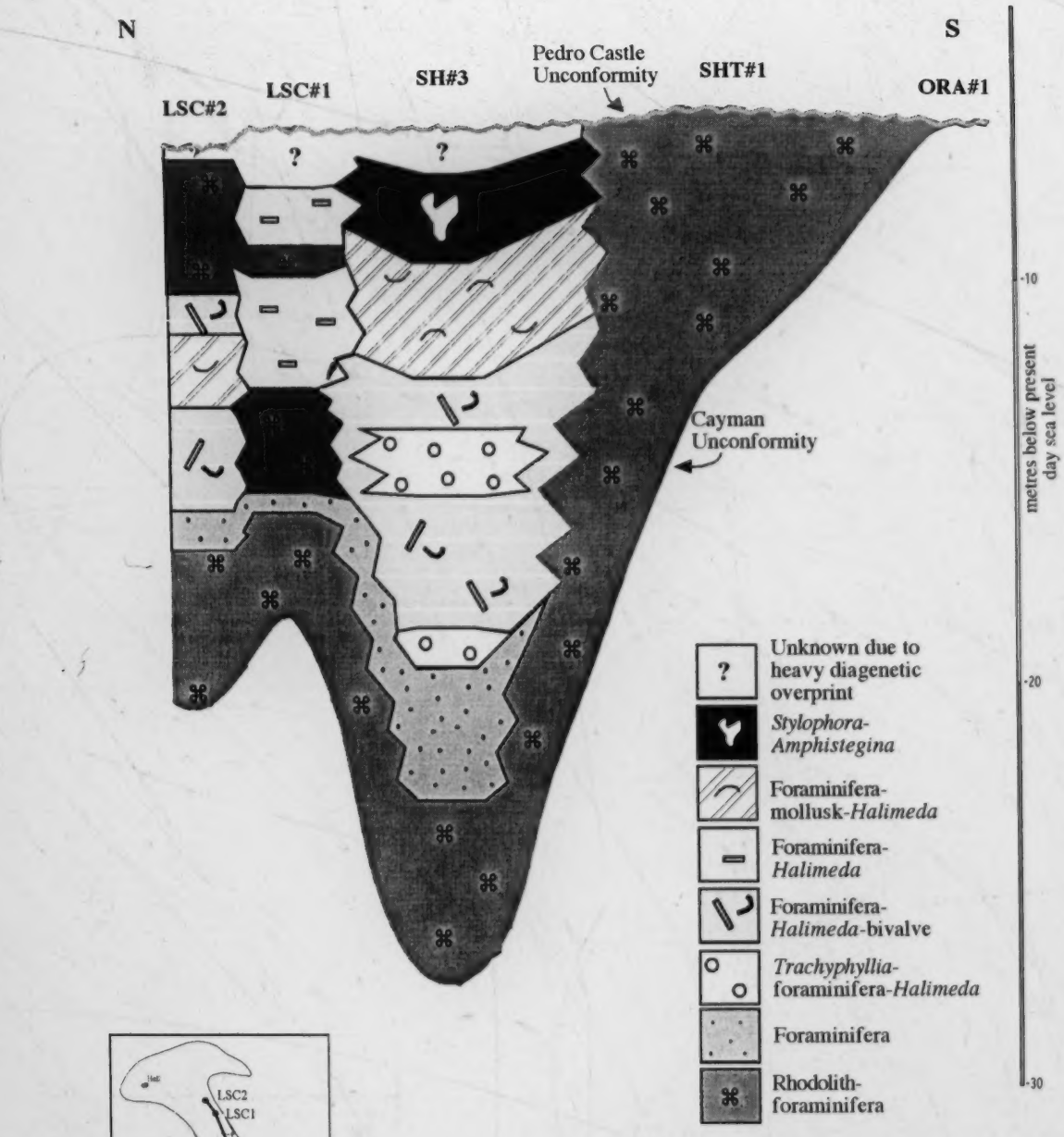


Figure 3.13. North-south cross section showing distribution of Pedro Castle facies on the western peninsula of Grand Cayman.



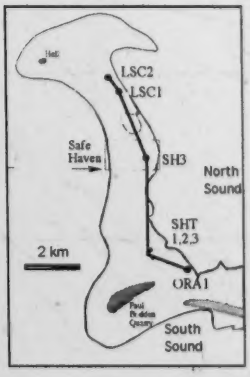
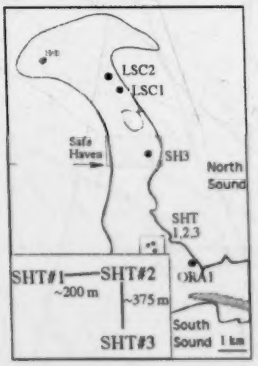
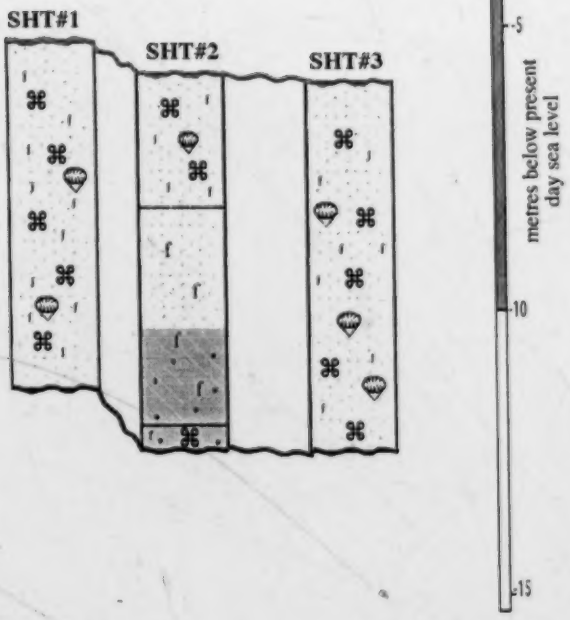


Figure 3.14. Facies architecture for the Pedro Castle Formation facies in the western transect area. The facies are laterally continuous and show a defined vertical succession.





Lithology

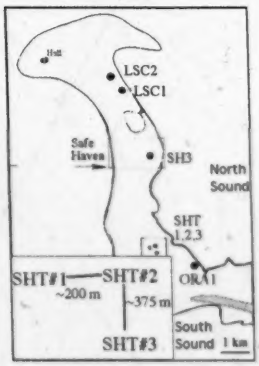
- Grainstone
- Packstone
- Wackestone
- Mudstone

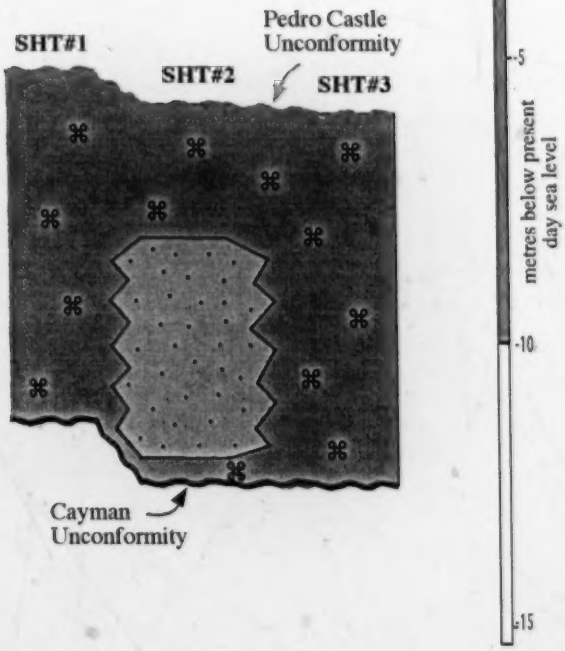
Facies

- Rhodolith-foraminifera
- *Trachyphyllia*-foraminifera- *Halimeda*
- Foraminifera
- Foraminifera-*Halimeda*-bivalve
- Foraminifera-mollusc-*Halimeda*
- Foraminifera-*Halimeda*
- *Stylophora-Amphistegina*

Heavy diagenetic overprint

Figure 3.15. Distribution of the Pedro Castle Formation facies in wells SHT#1,SHT#2, SHT#3.





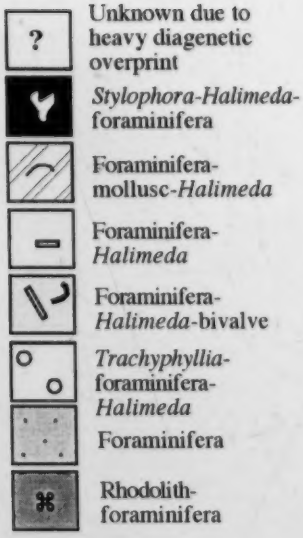


Figure 3.16. Facies architecture for the Pedro Castle Formation in the SHT wells.

Pedro Castle Formation, directly, or almost directly, above the rhodolith-foraminifera facies.

Bivalves and *Halimeda* are abundant in the middle of the preserved Pedro Castle Formation. The foraminifera-*Halimeda*-bivalve facies was deposited above the foraminifera facies in wells SH#3 and LSC#2. There are also a high number of mollusks and *Halimeda* in the rhodolith-foraminifera facies that directly overlies the foram facies in the laterally adjacent well LSC#1. The percentage of mollusks, especially robust bivalves, peaks in the foraminifera-mollusk-*Halimeda* facies in wells SH#3 and LSC#2, then decreases with a return to the foraminifera-*Halimeda*-bivalve facies. Robust bivalves are common in LSC#1 towards the top of the lower interval of the foraminifera-*Halimeda* facies. Well LSC#1 contains numerous *Halimeda* and rhodoliths, with intervals of the rhodolith-foraminifera and foraminifera-*Halimeda* facies also being present upsection. The other wells (SHT#1, #2, #3) in the study area have stratigraphically short, shallow sections of the Pedro Castle Formation that do not progress above the rhodolith-foraminifera and foraminifera facies.

Mollusk and *Halimeda* rich facies are reported from similar stratigraphic intervals in the Safe Haven (Wignall, 1995) and Lower Valley Transect areas (Arts, 2000), but in these areas there is a clearer upsection succession from mollusk dominated facies to *Halimeda* dominated facies.

The upper part of the Pedro Castle Formation in the study area is partially to completely obscured by severe diagenetic overprinting. The *Stylophora-Amphistegina* facies was deposited near the top of Pedro Castle Formation in well SH#3. This well contains the thickest section of the Pedro Castle Formation in the western transect. *Stylophora* facies were also noted in the upper part of the Pedro Castle Formation in the Safe Haven (Wignall, 1995) and Lower Valley Transect areas (Arts, 2000). In well LSC#2 the rhodolith-foraminifera facies is the uppermost Pedro Castle facies, with corals more commonly serving as the nucleus material towards the top of the section. The distribution of free-living corals without algal encrustation is patchy. The rhodolith-foraminifera facies is also found near the top of the formation in well LSC#1.

There is no evidence of reefs or biohermal buildups in the Pedro Castle Formation of the study area. Two intervals of the *Trachyphyllia*-foraminifera-*Halimeda* facies with

dense concentrations of free-living corals are located in the middle of the Pedro Castle Formation in well SH#3, but these are limited in lateral extent. In the Pedro Castle Formation of the Safe Haven area the *Trachyphyllia*-foraminifera-*Halimeda* facies is found as isolated pods that are most commonly associated with topographic highs (Wignall, 1995). This facies is not described from the Lower Valley or Patrick Island Lagoon Transects (Arts, 2000).

Skeletal allochem distribution is more consistent in the Pedro Castle Formation than in the Cayman Formation. Robust molluscs are most common in the stratigraphically lower and middle parts of both the Safe Haven (Wignall, 1995) and western transect areas. Wignall (1995) reported that pelagic foraminifera are most common in the upper 10 m of the Pedro Castle Formation in the Safe Haven area. This corresponds to a rough upsection increase in the percentage of pelagic foraminifera r[illegible]tive to the total number of foraminifera in the study area. An upsection decrease in the percentage of *Archais* and miliolinid foraminifera was reported from the Safe Haven area, but such a decrease is only evident in this study in well SH#3. This is the deepest well in this study and it is the well that was included in both this study and Wignall's study of the Safe Haven area.

Discussion

The rhodolith-foraminifera facies represents the initial transgression onto the Cayman Unconformity on western Grand Cayman. It was deposited in turbulent, shallow water, less than 20 m deep, above wave base, but protected by the surrounding peripheral ridges from storms. The unconformity provided a hard ground for *Amphistegina* to colonize. Eroded fragments of the unconformity may have served as rhodolith nuclei. Normal marine conditions existed throughout this phase of deposition.

Energy levels were moderate to high during deposition of the foraminifera, foraminifera-*Halimeda*-bivalve, foraminifera-mollusk-*Halimeda*, and foraminifera-*Halimeda* facies. Water depths are difficult to determine for these facies due to a lack of framework corals and diagnostic fossil indicators. Deposition above normal wave base (~20-30 m) is suggested by abundant *Amphistegina* in sediments that are otherwise indicative of a restricted environment. These facies are interpreted as being deposited in

shallow interior waters that may have experienced restricted water circulation. Interbedding of the *Trachyphyllia*-foraminifera-*Halimeda* facies indicates that the restriction was intermittent, or that certain areas, possibly topographic highs, received well-circulated waters. The upsection increase in mud content and pelagic forams indicates that sea level continued to rise and that a connection to open seas became established.

The central and deepest well, SH#3, most clearly shows the deepening trend. The branching corals and the foram assemblage of the *Stylophora-Amphistegina* facies indicate that water circulation was unrestricted and may have been close to 30 m deep near the top of the formation. Increased numbers of free-living corals and rhodoliths with branching coral nuclei towards the top of well LSC#2 also indicate a gradual removal of restrictions to water circulation.

Controls on Deposition

Water depth and water energy were linked variables during deposition of the sediments that now form the Pedro Castle Formation. In general, water energy decreased as water depth increased (Figure 3.17). The underlying Cayman Unconformity initially controlled deposition. Water depth, energy, and circulation were determined by the topography of the bowl shaped depression. A gradual rise in sea level allowed shallow-water deposits to initially cover the entire unconformity surface. Each incremental rise in sea level covered more of the unconformity surface with water, resulting in shallow water conditions spreading out from topographic lows while the water deepened in the centre of the depression (Figure 3.18). This also resulted in sediment draping of the facies. Wignall (1995) recognised slight highs in the underlying Cayman Unconformity in the Safe Haven area. He interpreted these to be wave-cut terraces, formed by stillstands of short duration during the subsequent marine transgression. This suggests that the sea level rise although gradual, was not continuous.

As sea level increased, low energy facies accumulated in topographic lows and higher energy facies were deposited over topographic highs. Energy levels decreased upsection despite sediment filling of the topographic lows. This indicates that the rising

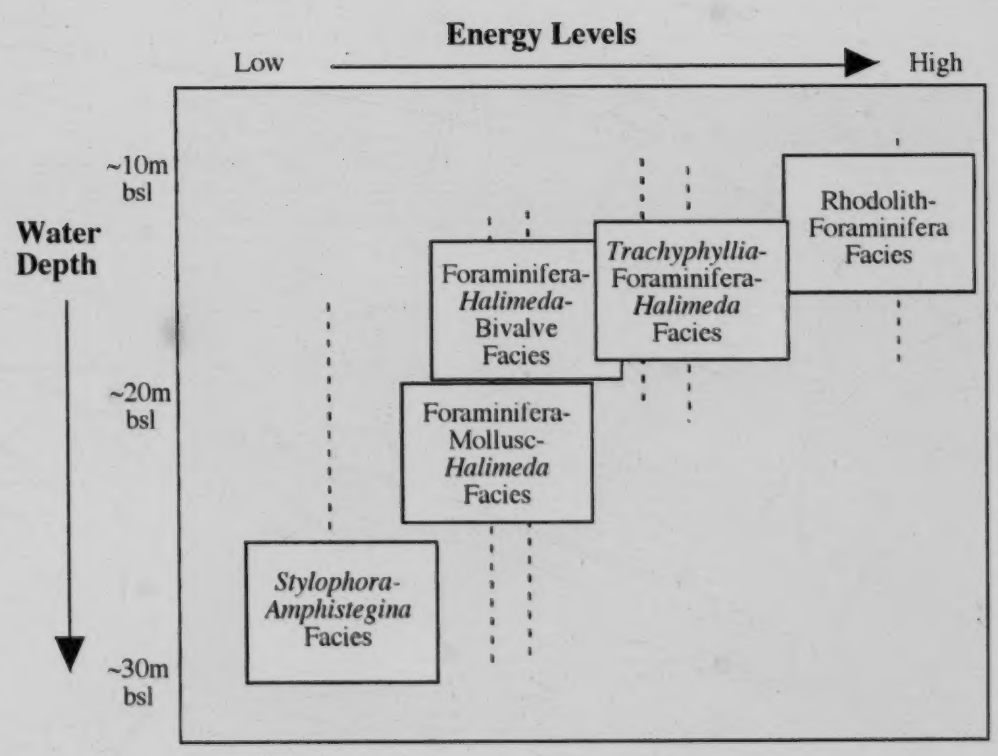


Figure 3.17. Shallower water depths correspond with increased energy levels for the facies of the Pedro Castle Formation. This indcates that these two variables are linked. The foram-*Halimeda* and foram facies are not plotted as water depth is undetermined for these moderate energy facies. The black dashed lines show the range of water depths possible for each formation.

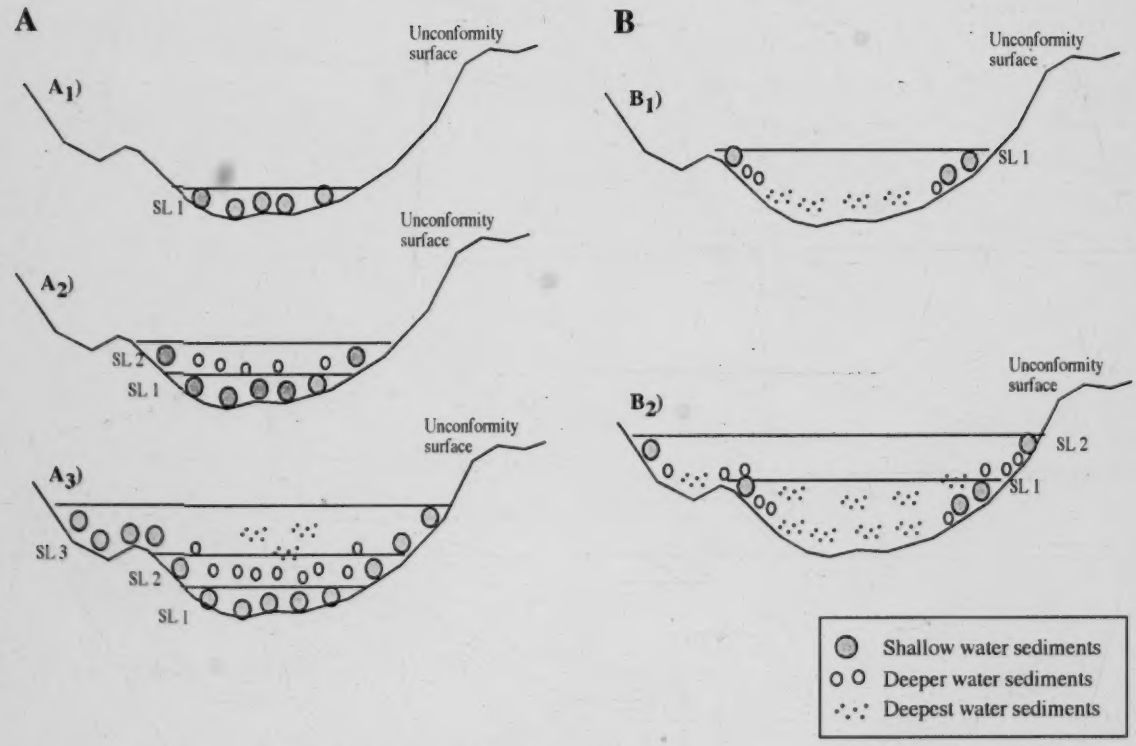


Fig. 3.18. A) Gradual increases in sea level result in layered sediments. B) Sharp increases in sea level result in shallow water sediments deposited peripheral to deeper water sediments.

sea level outpaced infill of the interior lagoon so that accommodation progressively increased. Water depth had become the main influence on deposition.

Summary

The topography of the Cayman Unconformity had a profound influence on the deposition of the Pedro Castle Formation. It controlled the initial substrate, determined water depths and restricted circulation. Laterally extensive facies with a defined vertical succession indicate that similar depositional conditions existed throughout western Grand Cayman at the same time. Gradually increasing water depths led to decreased energy levels and increased water circulation near the top of the section. Water depth increased from >20 m bsl to close to 30 m bsl in the middle of the western transect area.

Chapter 4: Depositional Controls on Modern Banks and Characterization of those Controls in the Miocene and Pliocene

Carbonate banks are isolated shallow water platforms surrounded by deep oceanic waters and thereby isolated from terrigenous clastic material. As a result, sea level changes and climate are the major controls on deposition (Jones and Desrochers, 1992).

Modern warm water carbonate banks are typically covered by less than 20 m of water (Jones and Desrochers, 1992). Marginal reefs and coarse peripheral sediments are common; interior waters are typically quiet areas where sandy mud and mud are deposited (Tucker and Wright, 1990; Jones and Desrochers, 1992). This pattern may be modified by factors such as periodic storms, winds, currents, or depths much deeper than that of the typical bank. Small banks commonly have distinctive facies patterns as the margins are subject to different storm and wave regimes (Tucker and Wright, 1990).

The duration and magnitude of physical-energy flux are major controls on the variability and characteristics of carbonate platform margins (Goldberg, 1983; Triffleman et al., 1992). The net energy flux is onto the platform along windward margins, fostering reef growth, island development, and the formation of skeletal sands (Trifleman et al., 1992). Spur and groove structures, biological zonation, and shallow back reef flats are common in high energy settings, such as the Bahamas Banks (Trifleman et al., 1992). Strong cross-bank energies can sweep sediments across banks and off open leeward margins; sometimes resulting in thick wedges of sand along leeward margins (Goldberg, 1983; Glaser and Droxler, 1991;Triffleman et al., 1992). Small (less than 2000 km^2), deep (deeper than 10 m) banks without a windward reefal rim may fail to keep up with rapid sea level rise due to net off-bank transport of sediments (Trifleman et al., 1992). Small banks are susceptible to drowning, as it is a short distance from any point on their bank top to the deep sea (Dominguez and Mullins, 1988; Triffleman et al., 1992). Larger banks with open or poorly developed rims, such as the Cay Sal Bank, Bahamas, may be biologically impoverished, failing to build reefal frameworks as a result of frequent resuspension and off-bank transport of sediment (Goldberg, 1983).

Modern intermediate depth banks (10-45m) in the Caribbean Sea, Gulf of Mexico, and the Bahamas are characterized by a wide array of sediments and an abundant, diverse coral dominated biota (Jones and Hunter, 1994b). Reefs are rare, usually restricted to shallower, windward margins (Jones and Hunter, 1994b). Sediments are commonly redistributed across the bank by currents and storms, resulting in homogenized coarse-grained deposits with relatively little mud (Glaser and Droxler, 1991; Jones and Hunter, 1994b). Deeper water banks are out of the zone of optimum hermatypic coral growth. At 50 m bsl on the Flower Garden Banks, Gulf of Mexico, coralline algae becomes the dominant frame builder and sediment contributor, (Minnery, 1990).

The modern Caribbean Sea is strongly influenced by steadily blowing easterly Trade Winds and the strong northwest Caribbean current (Wilber, 1987). Trade winds are interrupted only by severe winter storms that approach from the northwest in response to North American continental cold fronts (Roberts and Sneider, 1982; Blanchon, 1995; Li, 1997; Triffleman et al, 1992). These storms may temporarily reverse surface-current flow from northwestward to southeastward (Triffleman et al, 1992).

On Grand Cayman the trade wind system causes waves to shift from the northeast to the east to the southeast, so that the greatest shore wave power is focused on the eastern, northeastern, and southeastern shores (Figure 4.1) (Roberts and Sneider, 1982; Blanchon, 1995). Atlantic tropical storms, including two major hurricane paths, also approach Grand Cayman from the east (Wilson, 1998). Clasts torn up by these storms form the core of a fringing reef complex that is largely independent of underlying shelf topography (Blanchon, 1997). This complex reduces the amount of energy that impacts windward margins.

Wind and waves set up a mean drift current that sweeps around Grand Cayman, losing momentum and dropping significant volumes of sediment on the western lee flanks (Roberts and Sneider, 1982). The flanks are unstable, unsuitable for the initiation and subsequent development of reefs, and as such become reworked by current action. This process of accumulation and redistribution of sediments is common on lee sides of islands (Roberts and Sneider, 1982). The western lee flanks of the island are also modified by severe winter storms, or Nor'-westers'. These storms generate strong

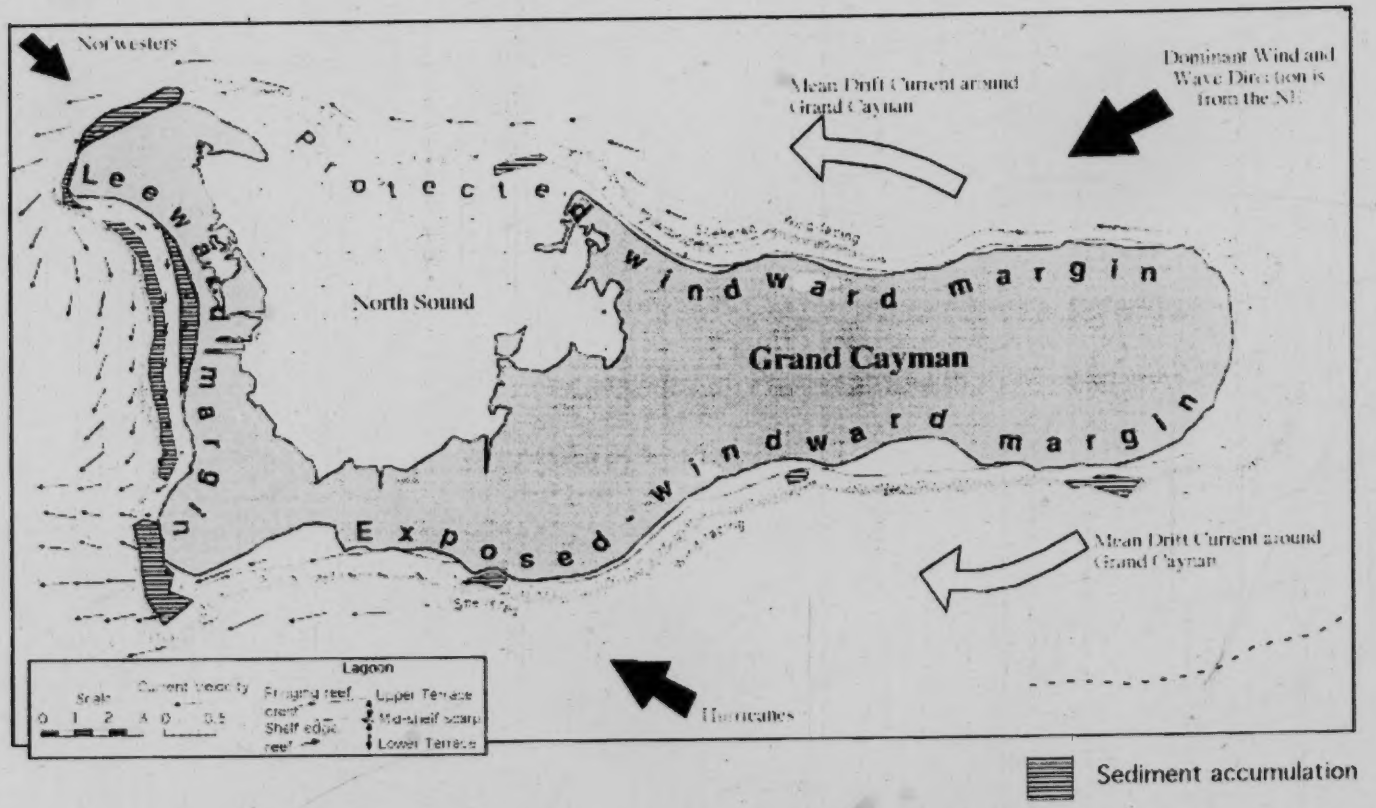


Figure 4.1. Orientation of storms, winds, and currents affecting modern Grand Cayman. Reef distribution, areas of extensive sediment accumulation, and bathymetry are also shown. Modified from Blanchon (1995) and Roberts and Sneider (1982).

onshore waves with a deep wave base and the capacity to move substantial quantities of sand across the shelf and homogenize faunal and floral assemblages (Blanchon, 1995; Li, 1997).

Miocene and Pliocene Wind and Current Patterns

Caribbean wind patterns in the Miocene and Pliocene were similar to modern patterns, with possibly accelerated wind strength during the Miocene due to climatic deterioration (Hine et al., 1994; Nesbitt and Young, 1997). Surface current directions and strengths, however, changed dramatically during the Middle and Late Miocene (Itturalde-Vinent and MacPhee, 1999) (Figure 4.2). Prior to the Middle Miocene water transport between the southern and northern Caribbean basins was restricted due to the Nicaraguan Rise, a neritic carbonate megabank extending from Nicaragua and Honduras to Jamaica (Hine et al., 1994; Cunningham et al., 1995; Roth et al., 2000). Atlantic waters were carried by the Circumtopical Current through the southern Caribbean and the Central American seaway into the Pacific (Figure 4.3) (Itturalde-Vinent and MacPhee, 1999; Roth et al., 2000). The Middle Miocene opening of two main seaways in the Nicaraguan Rise simultaneous to the gradual closure of the Central American Seaway established or greatly intensified the weak Caribbean, Loop and Gulf currents (Donnelly, 1989; Droxler, 1995; Itturalde-Vinent and MacPhee, 1999; Kameo and Sato, 2000; Roth et al., 2000). This allowed Atlantic waters to flow into the northern Caribbean basin and resulted in carbonate dissolution in the previously isolated, carbonate rich waters (Roth et al., 2000).

Opening and closing of the Central American seaway and varied flow across the Nicaraguan Rise throughout the Late Miocene and early Pliocene prevented establishment of the existing pattern of Caribbean surface currents until ~4 Ma (Iturralde-Vinent and MacPhee, 1999). Atlantic tropical storms were less frequent and intense during times when the Central American Seaway was open (Nesbitt and Young, 1997; Iturralde-Vinent and MacPhee, 1999). Grand Cayman is currently sheltered from high latitude swell by surrounding land masses (Roberts and Sneider, 1982), and appears to have been similarly sheltered in the Miocene and Pliocene (Figure 4.3).

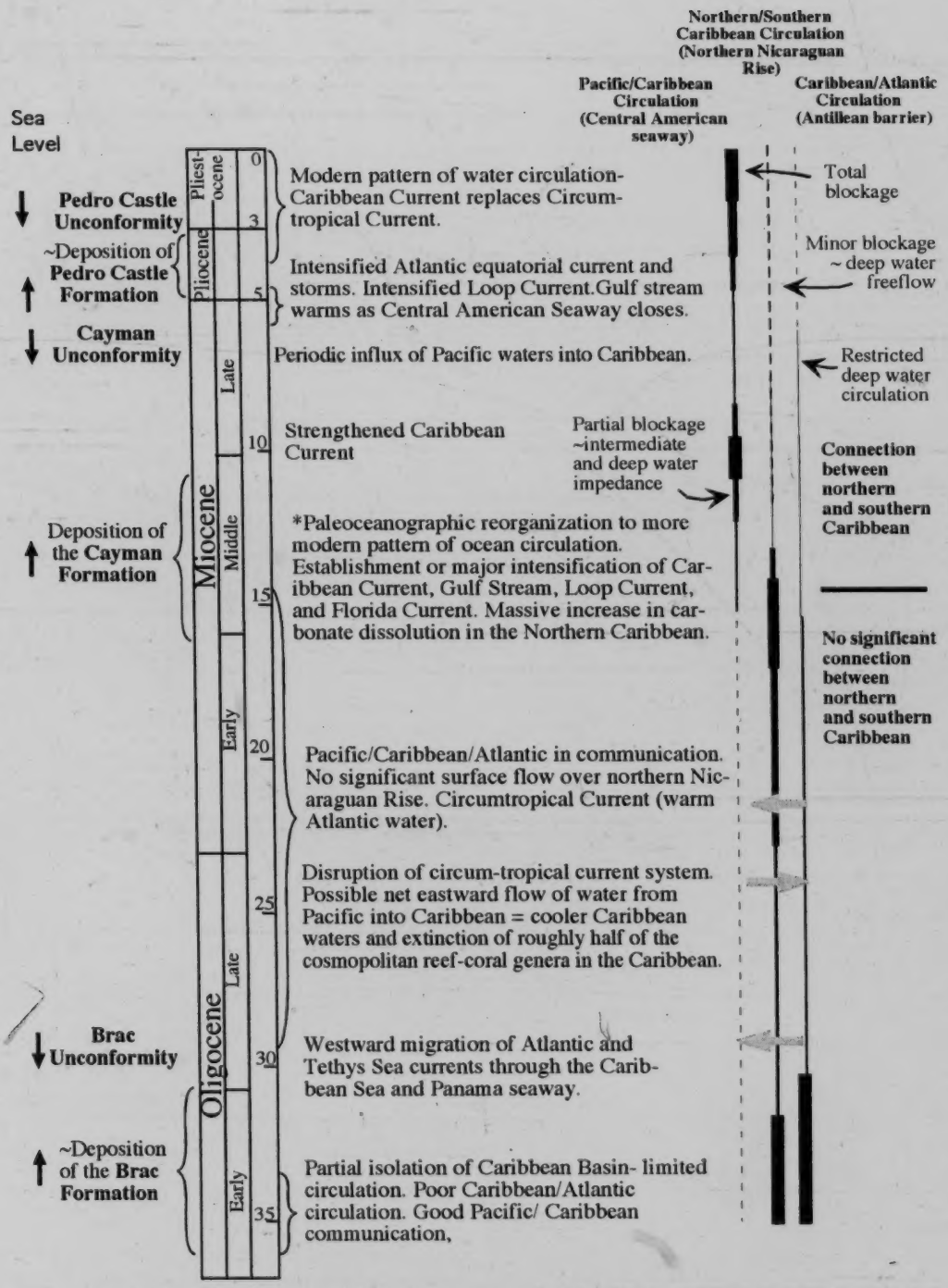

Northern/Southern Caribbean Circulation (Northern Nicaraguan Rise)
Pacific/Caribbean Circulation (Central American seaway)
Caribbean/Atlantic Circulation (Antillean barrier)
Sea Level
Pedro Castle Unconformity
~Deposition of Pedro Castle Formation
Cayman Unconformity
Deposition of the Cayman Formation
Brac Unconformity
~Deposition of the Brac Formation
Pliest-ocene
Pliocene
Miocene
Late
Middle
Early
Oligocene
Late
Early
0
3
5
10
15
20
25
30
35
Modern pattern of water circulation- Caribbean Current replaces Circum-tropical Current.
Intensified Atlantic equatorial current and storms. Intensified Loop Current.Gulf stream warms as Central American Seaway closes.
Periodic influx of Pacific waters into Caribbean.
Strengthened Caribbean Current
*Paleoceanographic reorganization to more modern pattern of ocean circulation. Establishment or major intensification of Caribbean Current, Gulf Stream, Loop Current, and Florida Current. Massive increase in carbonate dissolution in the Northern Caribbean.
Pacific/Caribbean/Atlantic in communication. No significant surface flow over northern Nicaraguan Rise. Circumtropical Current (warm Atlantic water).
Disruption of circum-tropical current system. Possible net eastward flow of water from Pacific into Caribbean = cooler Caribbean waters and extinction of roughly half of the cosmopolitan reef-coral genera in the Caribbean.
Westward migration of Atlantic and Tethys Sea currents through the Caribbean Sea and Panama seaway.
Partial isolation of Caribbean Basin- limited circulation. Poor Caribbean/Atlantic circulation. Good Pacific/ Caribbean communication,
Total blockage
Minor blockage ~ deep water freeflow
Restricted deep water circulation
Partial blockage ~intermediate and deep water impedance
Connection between northern and southern Caribbean
No significant connection between northern and southern Caribbean

Figure 4.2. Timeline of events affecting currents in the Caribbean region (Frost, 1977a; Haq et al, 1987; Itturalde-Vinent and MacPhee, 1999; Jones et al., 1994; Jones and Hunter, 1994b; Nesbitt and Young, 1997; Roth et al., 2000; Arts, 2001). Width of bars on the right refers to the amount of obstruction to water movement. Grey arrows indicate direction of water movement.

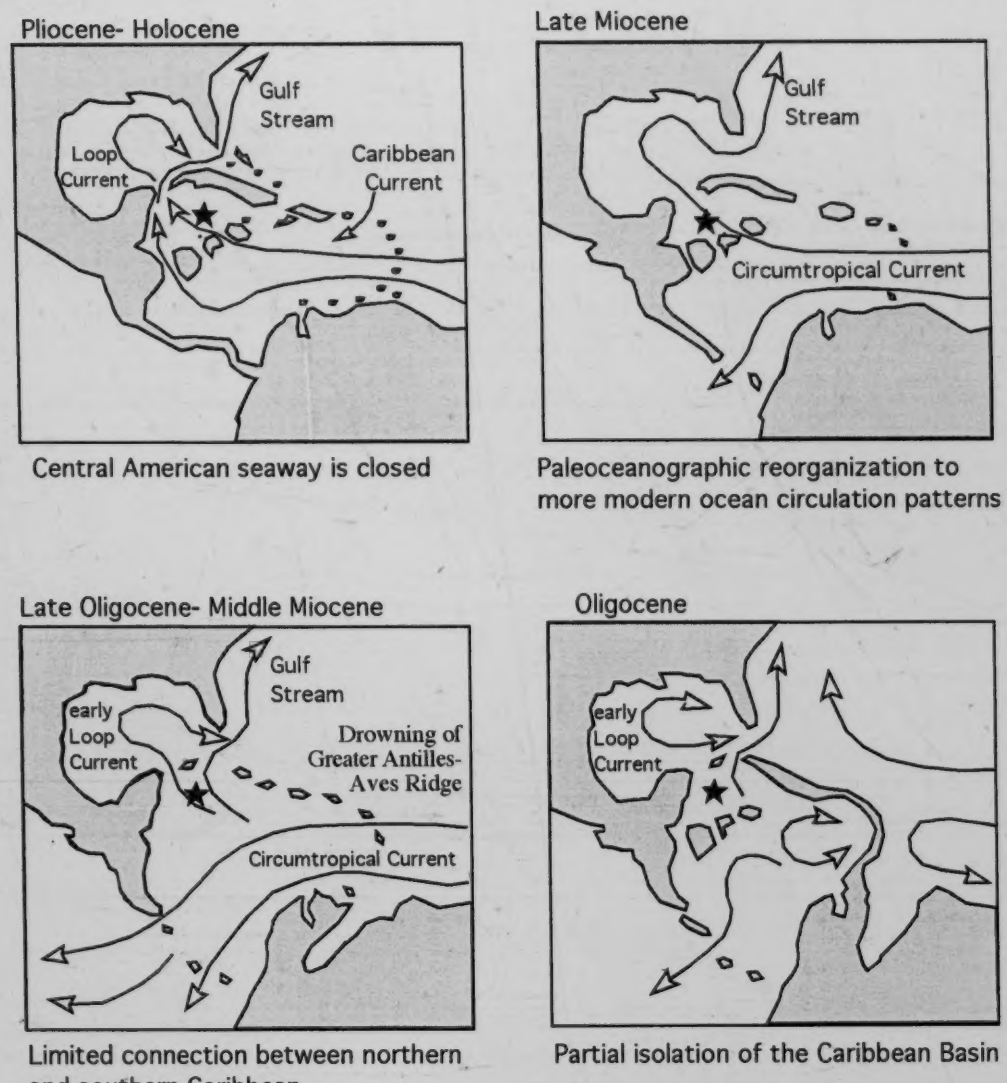


Figure 4.3. Evolution of Cenozoic paleocurrent patterns for the Caribbean region. Modified from Iturralde-Vinent and MacPhee, 1999.

Climate and Sea level

The paleoclimate of the Miocene was relatively cool, with late Early and Middle Miocene sea levels higher than present day levels (Figure 4. 4) (Vail and Hardenbol, 1979; Hallam et al., 1984; Haq et al., 1987). Temperatures in the tropical latitudes, however, were not significantly different from today (Wignall, 1995). Sea level rose throughout the late Early and early Middle Miocene to a major highstand position in the middle Middle Miocene. Sea level fell, then rose again to a second highstand position in the late Middle Miocene. Paleotemperatures cooled throughout the Miocene culminating in a rapid cooling in the Latest Miocene/ Earliest Pliocene (Kemp and Frakes, 1973; Shackleton and Kennett, 1973). Expanded Southern Hemisphere glaciation at the end of the Latest Miocene/ Earliest Pliocene resulted in sea level drops of at least 40 m (Berggren and Haq, 1976; Pigram et al, 1992; Jones and Hunter, 1994a; Arts, 2000). Sea level changes were rapid; the Late Miocene lowstand is thought to have lasted only about 1.5 my (Jones and Hunter, 1994a).

Paleoceanographic data indicates that the Pliocene was warmer than the Miocene, with tropical and subtropical ocean temperatures similar to slightly warmer than that of today (Cronin and Dowsett, 1993; King, 1996; Reijmer, et al, 1999). Northern latitudes were significantly warmer (3-5°C), however, due to northward heat transport by Gulf Stream-North Atlantic drift (Cronin and Dowsett, 1993). Glacial melting caused sea level to rise up to 40 m above present day levels (Shackleton and Opdyke, 1977; Cronin and Dowset, 1993; Arts, 2000). Lesser highstand levels were reached during two subsequent Pliocene transgressive cycles (Fig 4.4). Late Pliocene/ Early Pleistocene glaciation in the northern hemisphere caused a severe drop in sea level to below present day levels. Northern Hemisphere glaciation may ultimately have been tied to the closure of the Central American Seaway which strengthened the Gulf Current, increasing warm water transport to northern latitudes and prompting precipitation and glaciation (Nesbitt and Young, 1997).

Miocene and Pliocene coral assemblages

Paleoclimatic and current changes impacted Caribbean reef building fauna. In the Late Oligocene, Caribbean coral reefs were widespread, well developed, and highly

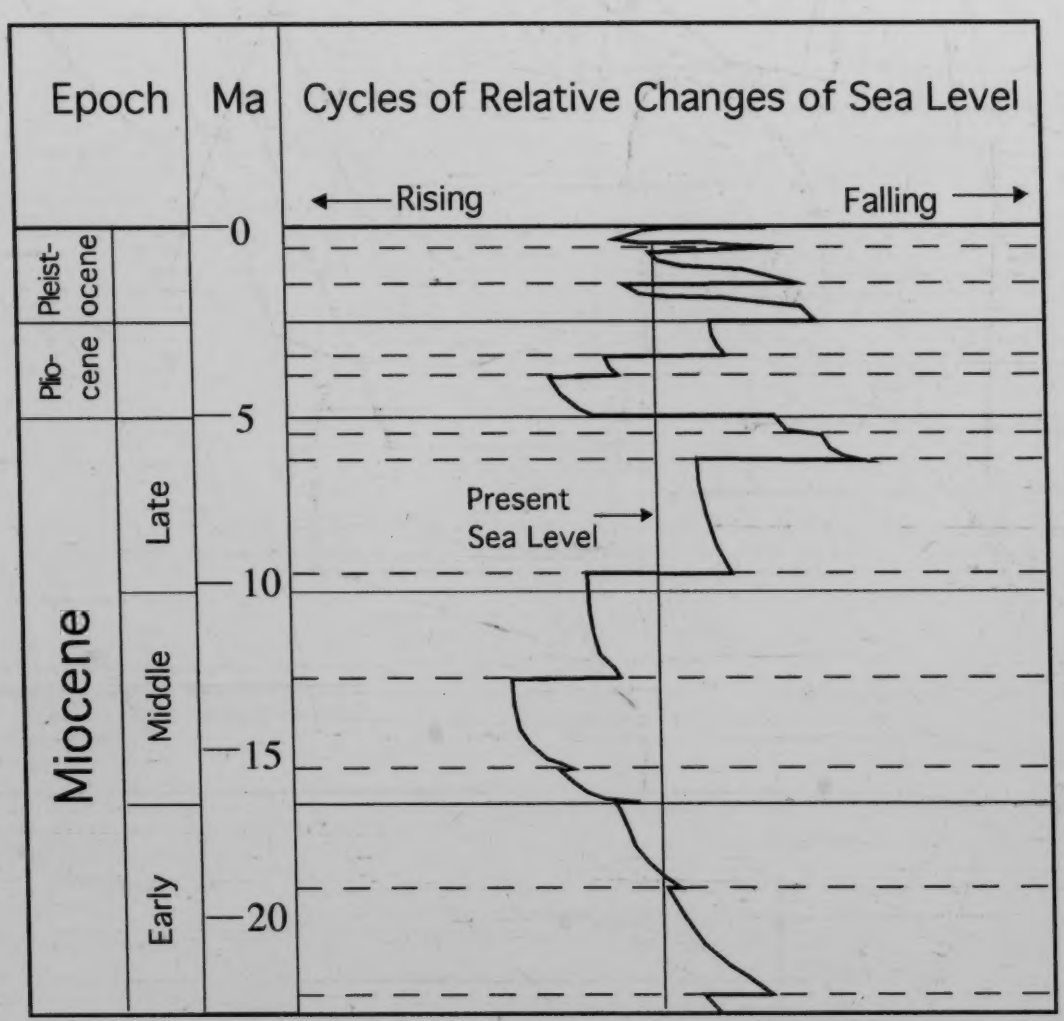


Figure 4.4. Third order sea level curves for the Miocene and Pliocene (modified from Vail *et al.* 1977).

diverse (Johnson, 1999). The extinction of roughly half of the Caribbean cosmopolitan reef-coral genera at the end of the Oligocene has been tied by Frost (1977b) to a current reversal that induced a net influx of cool, low salinity Pacific waters into the Caribbean. Throughout the Early and Middle Miocene coral species diversity increased; however significant reef tract development did not return to the Caribbean until the Pleistocene (Frost, 1977b; Johnson, 1999). The dominant coral species assemblages of the Early and Middle Miocene included branching and massive *Porites*, *Goniopora*, *Stylophora*, and *Monastrea* (Frost, 1977b). Corals continued to recover in the Pliocene and reefs became more numerous. Ramose species of *Stylophora* were abundant, occupying much of the ecological niche of *Acropora cervicornis* on modern reefs (Frost, 1977a). The extinction of roughly 80% of the Caribbean coral species at the end of the Pliocene has been associated with the closure of the Central American Seaway, intensification of the Gulf Current, and an increase in sea-level oscillation due to intensification of northern hemisphere glaciation (Budd, Peterson, and McNeill., 1998; Johnson, 1999).

Implications for Deposition of the Cayman and Pedro Castle Formations

Cayman Formation

The Cayman Formation is thought, based on fauna and stratigraphic setting, to have been deposited during the Middle Miocene (Jones et al., 1994). It is known that Middle Miocene temperatures were similar or slightly cooler than today, sea level was higher, with major highstand positions in the middle and late Middle Miocene, the Caribbean current was weaker, NE trade winds may have been stronger, and tropical storms may have been less common. Branching and massive corals were common, but reefs were not. It is probable then that windward margins were not protected by extensive fringing reefs, leaving eastern margins exposed to high wave energies. No evidence of reefal buildups has been found in Cayman Formation core or outcrop at either the eastern (Wilson, 1998) or southeastern (Montpetit, 1998) Grand Cayman study sites. Massive and branching corals are common however, and *Stylophora* thickets are thought to have baffled currents on the eastern margin (Wilson, 1998). Moderate to high energy facies dominate both locations, and are interpreted at the southeast location to be the product of a current swept open bank (Montpetit, 1998). Eastern margin deposits are characterized

by high frequency paleoenvironmental variations, the result of periodic storm events (Wilson, 1998).

Sedimentary structures associated with currents are very rare in cores along the western transect. Wignall (1998) interpreted Safe Haven's (centrally located on Grand Cayman's western peninsula) sediment distribution as unaffected by cross-bank currents. No clear evidence of cross-bedding or sedimentary structures were observed in the sand plain facies that makes up most of the Cayman Formation at Safe Haven. Thick, uninterrupted sediment accumulations also led Wignall (1998) to suggest that Safe Haven was either sheltered from cross bank currents, or located in an area where sediment was preferentially trapped by antecedent morphology or reef buildup.

Evidence for cross-bank currents does exist on the leeward western bank margin. The Safe Haven reef and its N-S orientation (Wignall, 1998) (Figure 2.21) suggests currents with a dominant E-W (W-E) orientation. Safe Haven and the lower Cayman Formation in the western transect are dominated by sandy, moderate to high energy facies with localized patch reefs; features common to unrimmed banks (Jones and Desrochers, 1992). The dominant coral morphology of the Cayman Formation along the western margin is a branching form that is well adapted to currents and high sedimentation rates.

Thick sediment accumulations also suggest cross-bank currents. Waves would have eroded unprotected windward margins, generating sediment that would have been swept westward around and across the bank, with little northern drift. Momentum loss and baffling by branching corals would have led to sediment fall out and thick sediment accumulations. Reworking by Nor'westers, bioturbation, and/ or diagenesis could have erased sedimentary structures. Any remaining sedimentary structures may have been missed due to the scale of the studied small diameter core.

Reefal buildups are rare in the Cayman Formation; however, most of the documented small patch reefs and isolated buildups are located on western Grand Cayman (Wilson, 1998). This may be due to the relatively lower energy regime of the leeward margin. Patch reefs on the western part of Grand Cayman are comprised of branching corals, either dominantly *Porites,* or a mix of *Porites* and *Stylophora. Porites* formed pioneer reef communities in the Oligocene, and was one of the most important reef building corals of the Miocene (Frost, 1977; Foster, 1986). *Stylophora* was common

in deeper Oligocene reef environments and was abundant in the Miocene. These corals offered little surface area for sediment to settle on and removed accumulated sediment by tentacular movement. They were also fast growing; able to quickly rise above accumulated sediment, colonize unstable substrates, recolonize after storms, and survive high predation rates (Jones and Hunter, 1994). They are, however, unstable in rough water (James and Bouroque, 1992). High sedimentation rates and more moderate energy levels may have facilitated the establishment of branching corals on leeward margins. Baffling by the corals would have then increased sedimentation rates and reduced competition from other corals. The branching coral's rapid growth rates may have allowed them to form small reefs at a time when reef tract development was uncommon.

The Cayman Formation, assuming no significant dip, shows significant facies variation between the western transect, Safe Haven, Tarpon Spring Estates, and Roger's Wreck Point (Figures 1.2, 2.2). This is not unusual for small banks. Eastern (Wilson, 1998) and southeastern (Montpetit, 1998) Grand Cayman study sites are dominated by coarse coral and rhodolith rich, moderate to high energy facies. Cores along the western transect have moderate to high energy coralline algae and coral sands below a stratigraphic depth of ~30 m bpsl. Low energy *Stylophora* rich facies dominate above this. The Safe Haven study (Wignall, 1998), located centrally on the western peninsula, records mainly moderate to high energy skeletal sands surrounding a *Porites* reef that is located at a stratigraphic depth of 22 m to 32 m bpsl. The greatest lateral extent of the reef is at ~27 m to 30 m bpsl.

Montpetit (1998) tied changes at Tarpon Springs Estates to fluctuating sea levels (Figure 4.5). Wilson (1998), Wignall (1998), and this author however, have interpreted facies changes in their respective study areas as resulting from energy fluctuations, with minimal relative sea level change. All of the facies in the Cayman Formation on Grand Cayman have been interpreted as being deposited between 5 and 35 m below sea level.

Montpetit (1998) divided the Cayman Formation at Tarpon Springs Estates into three units separated by hardgrounds. Unit II, interpreted as being deposited in the shallowest water conditions (Montpetit, 1998), is stratigraphically located between approximately 50 m and 15 m bpsl- stratigraphically equivalent to most of the Cayman Formation on western Grand Cayman. This means sediment containing evidence of sea

level fluctuations may not have been preserved in western areas. It is also possible that small changes in relative sea level, not associated with hardgrounds, may have been missed. On the eastern margin slight changes in depositional depth may have been disguised or destroyed by rapid facies changes and storm events.

At an approximate stratigraphic depth of 30 m bpsl (Figure 2.16, 2.17) the Cayman Formation along the western transect (on Grand Cayman's western peninsula) transitions into an upper *Stylophora* dominated unit (depositional Unit II). This does not correspond with Montpetit's sea level curve (Figure 4.5) from southeastern Grand Cayman. This does, however, roughly correspond to the greatest east west lateral extent of the Safe Haven *Porites* reef (~28 m bsl). Estimated depositional depth is approximately the same for both the upper *Stylophora* dominated units and lower sandy units in the western transect. Energy levels, however, are lower and more laterally extensive during deposition of the upper unit, implying a change in current or wave activity.

Development of western margin reefs, like the Safe Haven reef, would have protected inner bank areas from northern storms. Not interpreted as a major barrier to swell and current energies, the Safe Haven reef was a barrier to shifting sands and may have reduced western sediment movement. Branching corals would have benefited from reduced abrasion by storm material. Fine sediment accumulation would have discouraged competition and promoted rapid coral growth. Establishment of *Stylophora* thickets would have further reduced local energy levels, stabilized sediment and increased collection of fine sediment by baffling current flow. *Stylophora* thickets may have gradually spread along the western margin, with the exception of the unprotected southern most areas. The development of the *Stylophora* facies association in well ORA#1, at 10 m below stratigraphic sea level (Figure 2.17), does correspond to a sea level rise interpreted in the Tarpon Springs Estates (Montpetit, 1998). The development of the *Stylophora* facies occurs at a much higher stratigraphic depth than in the rest of the western peninsula, possibly indicating that this area was unsuitable for coral growth until an increase in water depth reduced energy levels and produced a substrate muddy enough for *Stylophora* to colonize.

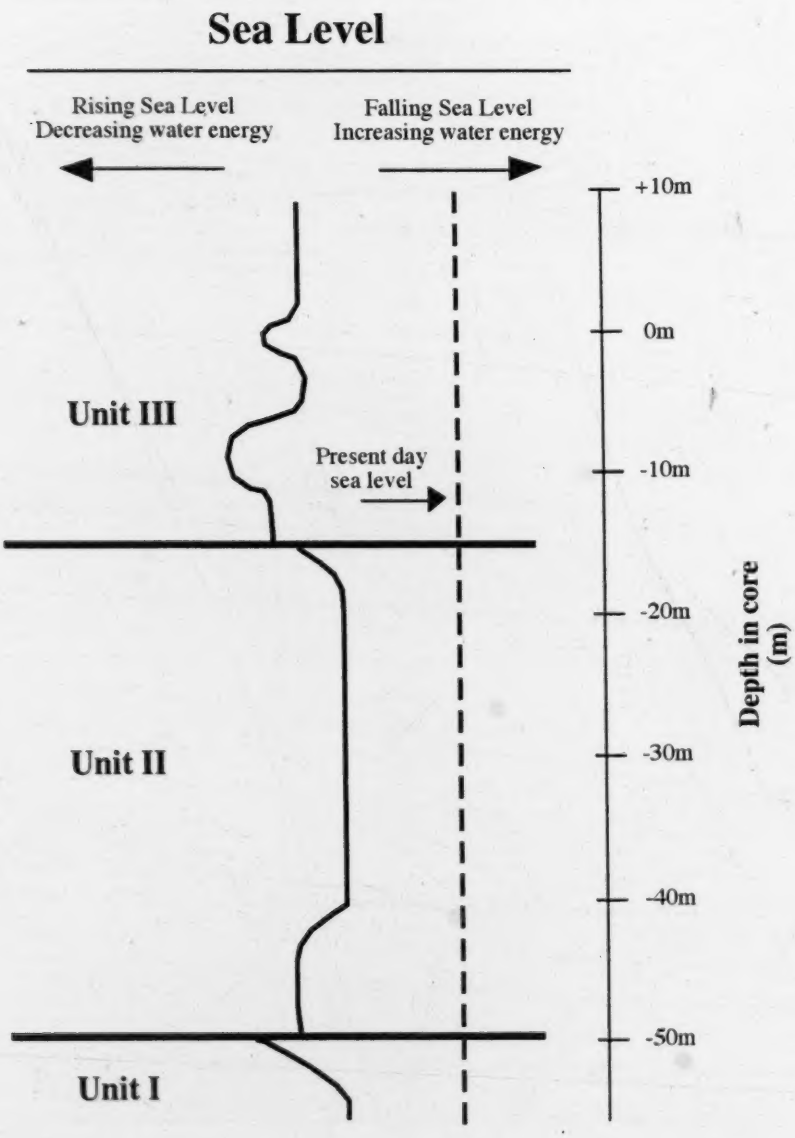


Figure 4.5. Relative sea level (water depth) and water energy curve for the Cayman Foramtion at Tarpon Springs Estates (modified from Montpetit, 1998).

Depositional depths were relatively static throughout deposition of the preserved Cayman Formation on western Grand Cayman. This suggests that the Cayman Formation was deposited during highstand conditions. However, erosion associated with lowstand conditions at the end of the Miocene removed much of the upper Cayman Formation from Grand Cayman.

Grand Cayman was an atoll-like island at the end of the Miocene; exposed by a sea level drop of at least 40 m (Jones and Hunter, 1994a; Arts, 2000). The uneven topography of the Cayman Unconformity (Figure 3.1) indicates a greater amount of bedrock dissolution took place on the western side of the island, probably due to higher annual rainfall (Jones and Hunter, 1994a). The raised rim that surrounds the inner lows of the Cayman Unconformity is a result of differential dissolution (Jones and Hunter, 1994a). The extensive amount of carbonate dissolution suggests that the climate was warm and wet.

Jones and Hunter, 1994a, have documented many karst features, including caves, sinkholes, and phytokarst associated with the unconformity. No clear soil horizons, however, have been found in the Cayman Formation. Any soils were most likely removed by erosion associated with the subsequent transgression (Jones and Hunter, 1994a; Wignall, 1995). Marine bioerosion modified the unconformity surface, removing a minimum of 1-3 m of rock (Wignall, 1995).

Pedro Castle Formation

Deposition of the Pedro Castle Formation was tentatively assigned by Arts (2000) to the first of three highstand events (fig 4.6) in the Pliocene (approximately 4-5 Mya). This was based on observation of a single transgressive cycle in western Grand Cayman. Arts (2000) reasoned that sediment was more likely to be removed from the top of a sequence than the base. Maximum Pliocene sea levels were reached during this initial transgressive cycle, providing the greatest chance for submergence of the island. However, the Pedro Castle Formation is unconformity bounded so parts of the formation may be missing. Strontium dating (Jones, 1994) had previously indicated deposition between 3-5 Ma; corresponding to the entire Pliocene. Deposition prior to the Pleistocene is definite as many of the Pedro Castle Formation corals (such as *Trachyphyllia bilobata,*

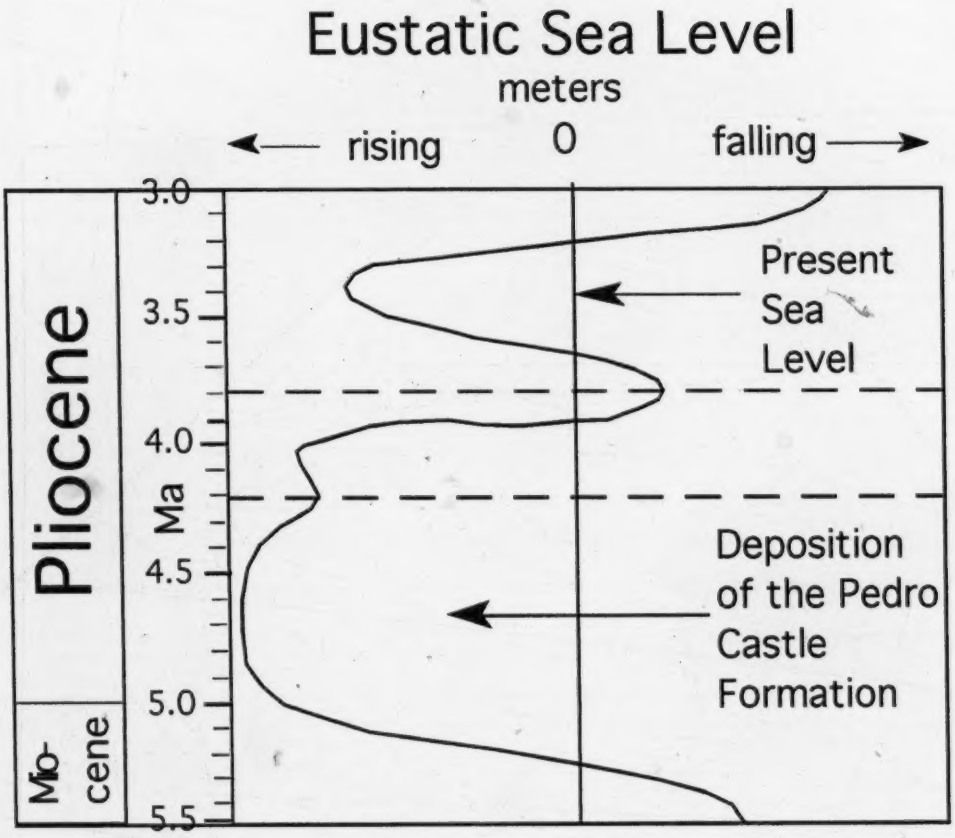


Figure 4.6. Third order sea level curve for the Miocene and Pliocene (modified from Arts 2000).

Porites baracoaensis, Stylophora spp., *Leptoseris* spp., and *Montastrea limbata*,) died out at the end of the Pliocene (Hunter, 1994).

A single transgressive cycle was also observed in the western transect cores, lending support to deposition during the initial Pliocene transgression. Gradually increasing water depths are indicated by the lateral extent of the Pedro Castle Formation facies, the facies' draping morphology over the Cayman Unconformity, and gradually deeper depositional environments. No depositional breaks were observed. The rhodolith-foraminifera facies directly overlies the Cayman Unconformity in all western Grand Cayman study areas. Any Pliocene sediments deposited prior to the preserved Pedro Castle sediments would have had to have been entirely removed, possibly with some of the Cayman Formation. It is more probable that the Pedro Castle Formation in western and southwestern Grand Cayman was deposited during the initial transgression and possible later sediments were removed by erosion.

Pliocene equatorial temperatures were similar to slightly warmer than modern temperatures. Sea level, however, was up to 40 m above present day levels in the early Miocene. Water circulation and wind patterns were very similar to modern conditions, suggesting waves and currents approached from the east. These forces would have been reduced and modified by the eastern and southeastern peripheral highs of the Cayman Unconformity.

Topography and rising sea level controlled deposition of the Pedro Castle Formation on western Grand Cayman. The Cayman Unconformity had a topographic relief of at least 11.6 m in the study area, and almost 40 m over the entire island. Eastern Grand Cayman must have been exposed or only shallowly submerged during deposition of the Pedro Castle Formation. Broken peripheral highs also existed to the south and the north of the study area. These topographic highs protected western Grand Cayman from strong waves and hurricanes. The lesser western peripheral high buffered against Nor'-westers'. The Pedro Castle Formation on western Grand Cayman was deposited in an interior lagoon that was intermittently restricted from the open sea.

The unconformity surface determined initial water depth, provided the initial substrate and may have been a source of rhodolith nucleii. Depositional energy levels were linked to water depth in a generally inverse relationship. When sea level was too

low water circulation became restricted in the western bowl shaped depression. Reefs should have been more common than in the Miocene, and may have developed, then been eroded away from more eastern and southeastern locations. Dense concentrations of free living corals were associated with topographic highs in the Safe Haven study area, but although identified in the western transect study they are not associated with topographic highs.

Summary

The Cayman and Pedro Castle Formations in the study area are both shallow warm water carbonates, deposited in water 35 m deep or less. Sea level was static during deposition of the Cayman Formation, suggesting deposition during an extended Middle Miocene highstand. Current and storm deposits, indicative of a Gulf Current, support this timing. A regional lack of significant Miocene reef development and no evidence of reefs on eastern Grand Cayman indicate an unprotected windward margin. Cross bank currents swept the bank, moving sediment westward. Sediment loss off the western margin was reduced by momentum loss, baffling by branching corals and reworking by Nor'-westers'.

Pedro Castle sediments were deposited during a gradual sea level rise, strongly suggesting deposition during the initial Pliocene transgressive cycle. Sediment infilled the topographic lows of the Cayman Unconformity. Remnant peripheral highs of the Cayman Unconformity partially surrounded the western depression, creating a western interior lagoon. The topography of the unconformity determined initial water depth and controlled depositional energy levels.

Conclusions

The study of the Cayman and Pedro Castle Formations in seven cores from Grand Cayman's western peninsula has produced the following conclusions:

1) The Cayman Formation in the western transect area is a warm water carbonate deposited in water less than 30 m deep, and commonly less than 20 m deep. Deposition took place under two distinct depositional regimes controlled primarily by relative water energy. The lower unit records moderate to high energy conditions with low sedimentation rates. The upper unit records lower energy conditions and higher sedimentation rates, with moderate energy incursions. Depositional setting was the leeward side of an open bank subject to cross bank currents and periodic storms.
2) The Cayman Formation, assuming no significant dip, shows significant facies variation between the western transect, Safe Haven, Tarpon Spring Estates, and Roger's Wreck Point. The upper unit of the Cayman Formation in the western transect area has an overall muddier texture than other study sites. Western margin reefs, such as the Safe Haven Porites reef may have protected this inner bank area.
3) Sea level was static during deposition of the Cayman Formation, suggesting deposition during an extended Middle Miocene highstand. Current and storm deposits, indicative of a Gulf Current, support this timing.
4) The Pedro Castle Formation was deposited in water that gradually increased in depth from less than 20 m bsl to close to 30 m bsl. Energy levels decreased as water depth increased. Topography and rising sea level were the main controls on deposition.
5) The Pedro Castle Formation can be correlated across western Grand Cayman. This indicates similar depositional conditions existed throughout western Grand Cayman at the same time.
6) A single transgressive cycle with no observed depositional breaks suggests that the Pedro Castle Formation was deposited during the initial Pliocene transgression.
7) The percentage of dolomite in the Pedro Castle Formation consistently decreases upsection. Mineralogy does not appear to be tied to facies type.

References

Arts, A., 2000, Sedimentology and stratigraphy of the Pedro Castle Formation S.W. Grand Cayman, B. W. I. [unpublished M.Sc. thesis]: University of Alberta.

Basan, P.B., 1973, Aspects of sedimentation and development of a carbonate bank in the Baracuda Keys, South Florida: Journal of Sedimentary Petrology, v. 43, no. 1, p. 42-53.

Beanish, J., 2000, Sedimentology of a current- dominated lagoon: Case study of South Sound, Grand Cayman, B. W. I. [unpublished M.Sc. thesis]: University of Alberta.

Berggren, W. A., and Haq, B.U. 1976, The Andalusian Stage (Late Miocene): Biostratigraphy, Biochronology, and Paleoecology: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 20, p. 67-129.

Blanchon, P., Jones, B., Kalfleish, W., 1997, Anatomy of a fringing reef around Grand Cayman: storm rubble, not coral framework: Journal of Sedimentary Petrology, v. 67, no. 1, p. 1-16.

Blanchon, P., 1995, Controls on modern reef development around Grand Cayman [unpublished Ph.D. Thesis]: University of Alberta.

Bosence, D. W. J., 1991, Coralline algae: mineralization, taxonomy and paleocology; in Riding, R. ed. Calcareous Algae and Stromatolites: Springer-Verlag, Berlin, Germany, 98-113.

Brunt, M., et al., 1973, The Pleistocene rocks of the Cayman Islands: Geological Magazine, v. 110, no. 3, p. 209-221.

Budd, A.F., Johnson, K.G., Edwards, J.C.,1989, Miocene Coral Assemblages in Anguilla, B.W. I., and their implications for the Interpretation of vertical succession on fossil reefs: Palios, v. 4, no. 3, p. 264-275.

Budd, A.F., Peterson, R.A., McNeill, D.F., 1998, Stepwise faunal change during evolutionary turnover a case study from the Neogene of Curacao, Netherlands Antilles: Palaios, v. 13, p. 170-188.

Case, J.E., MacDonald, W. D., Fox, P. J., 1990, Caribbean crustal provinces; seismic and gravity evidence, *in* G. Dengo and J. E. Case eds., The Caribbean Region (The Geology of North America; v. H), Geological Society of America, Boulder, Colorado, p. 15-36.

Coyne, M. A., 2003, Transgressive- Regressive Cycles in the Ironshore Formation, Grand Cayman, B.W.I. [unpublished M. Sc. thesis]: University of Alberta.

Cronin and Dowsett, 1993, PRISM: Warm Climates of the Pliocene: Geotimes, p. 17-19.

Crouch R.W., Poag C.W., 1979, *Amphistegina gibbosa D'orbigny* from the California Borderlands: The Caribbean Connection: Journal of Foraminiferal Research v. 9, no. 2, p. 85-105.

Chaproniere, B.C.H., 1975, Palaeolocolgy of Oligo-Miocene larger foraminifera, Australia: Alcheringa v. 1, p. 37-58.

Cunningham, D., Droxler, A., Hine, A.C., 1995, Neogene/Quaternary Evolution of Pedro Channel, northern Nicaragua Rise; the strikeslip induced breakup of a carbonate mega bank in a plate boundary zone: SEG Annual Meeting Expanded Technical Program, Abstracts with Biographies no. 65, p. 865.

Dominguez, L.L. and Mullins, H., 1988, Cat Island Platform, Bahamas an incipiently drowned Holocene carbonate shelf: Sedimentology, v. 35, p. 805-819.

Domning, D.P., 2001, Sirenions, seagrasses, and Cenozoic ecological changes in the Caribbean: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 166, no 1-2, p. 27-50.

Donnelly, T.W., 1989, Geologic history of the Caribbean and Central America, *in* Bally, W. and Palmer. A., eds., The geology of North America, v. A., An overview; G.S.A., Boulder, Colorado p. 299-321.

Droxler, A.W., 1995, Control of the last 35 M.Y. Caribbean tectonic evolution on interoceanic water exchange and heat/salt latitudinal transfer: Annual Meeting of the Geological Society of America, abstracts with program, p. A-153.

Embry, A. F., and Klovan J. E., 1971, A late Devonian reef tract on northeastern Banks Island, N.W.T.: Bulletin of Canadian Petroleum Geology, v. 19, p. 730-781.

Emery K.O., and Milliman, J.D., 1980, Shallow-water limestones from slope off Grand Cayman Island: Journal of Geology, v. 88, p. 483-488.

Foster, A.B., 1986, Neogene paleontology in the Northern Dominican Republic. 3.The family Poritidae (Anthozoa: Scleractinia): Bulletins of American Paleontology, v. 90, p. 45-123.

Frost, S., 1977a, Ecologic controls on Caribbean and Mediterranean Oligocene reef-coral communities, *in* Taylor, D.L., ed. Proceedings of the Third International Coral Reef Symposium: Geology v. 2; Rosential School of Marine and Atmospheric Science, Miami, p. 367-375.

Frost S., 1977b, Cenozoic reef systems of the Caribbean- prospects for paleological synthesis; *in* Frost, Weiss, and Saunders eds., Reefs and Related Carbonates- Ecology and Sedimentology: A.A.P.G., v. 4, Tulsa, Oklahoma, p. 93-109.

Gill, I., and Hubbard, D. K., 1985, Subsurface sedimentology of the Miocene-Plicoene Kingshill Limestone, St. Croix, U.S.V.I., *in* Crevello, P.D., and Harris, P.M., eds., Deep-Water Carbonates, Buildups, Turbidites, Debris Flows and Chalks; A Core Workshop; SEPM Core Workshop, v.6, p. 431-460.

Glaser, K.S., Droxler, A.W., 1991, High production and highstand shedding from deeply submerged carbonate banks, northern Nicaraguan Rise: Journal of Sedimentary Petrology, v.61, no. 1, p. 128-142.

Goldberg, W.M., 1983, Cay Sal Bank, Bahamas: a biologically impoverished physically controlled environment: Atoll Research Bulletin, no. 271, p. 1-17.

Goreau, T. 1963, Calcium carbonate deposition by coralline algae and corals in relation to their roles as reef builders: Annals New York Academy of Sciences, no. 109, p. 127-153.

Hallam, A., 1984, Pre-Quaternary sea-level changes; Annual Revue: Earth and Planetary Science, v.12, p. 205-243.

Haq, B., Hardenbol, J., Vail, 1987, Chronology of fluctuating sea levels since the Triassic; Science, v. 235, p. 1156-1157,

Hills, D.J., 1998. Rhodolite development in the modern and Pleistocene of Grand Cayman [unpublished M.Sc. thesis]: University of Alberta

Hine, A., Harris, M., Locker, S., Hallock, P., Peebles, M., Tedesco, L, Mullins, H., Snyder, S., Belknap, D., Bonzles, J., Neumann, A., Martinez, J., 1994, Sedimentary infilling of an open seaway: Bawihka Channel Nicaraguan Rise: Journal of Sedimentary Research, v. B64, no. 1, p. 2-25.

Holcombe, T.L., Ladd, J.W., Westbrook, G., Edgar, N.T., Bowland, C.L., 1990, Caribbean marine geology; Ridges and basins of the plate interior, *in* G. Dengo and J. E. Case eds., The Caribbean Region (The Geology of North America; v. H), Geological Society of America, Boulder, Colorado, p. 231-260.

Hubbard and Pocock, 1972, Sediment rejection by recent scleractinian corals: a key to paleo-environmental reconstruction: Geol. Rundschau v. 61, p.598-626.

Hunter, I.G., 1994, Coral associations of the Cayman Islands [unpublished Ph. D. thesis]: University of Alberta.

Iturralde-Vinent, M.A., MacPhee, R.D.E., 1999, Paleogeography of the Caribbean region: Implications for Cenozoic biogeography: Bulletin of the American Museum of Natural History, no. 238, pp. 95.

James, N.P., and Bourque, P.A., 1992, Reefs and Mounds, *in* Walker, R.G., and James, N.P., eds., Facies Models: Response to Sea Level Change; Geological Association of Canada, St. John's, p. 323-347.

Johnson, J.H., 1961,Limestone-Building Algae and Algal Limestones; Colorado School of Mines, Boulder, Colorado, 297 p.

Johnson, K. G., 1999, Middle Miocene recovery of reef-coral diversity but not reef building after the Caribbean Oligocene/ Miocene transition: Abstracts with Programs, Geological Society of America, v. 31, no. 7, p. 473.

Jones. B. 1994. Geology of the Cayman Islands, *in* Brunt, M. and Davies, J. eds., The Cayman Islands: Natural History and Biogeography: Kluwer, Netherlands, p.13-49.

Jones, B., and Hunter, I.G., 1989, The Oligocene-Miocene Bluff Formation on Grand Cayman: Caribbean Journal of Science, v. 25, no. 1-2, p. 71-85.

Jones B., and Hunter, I.G., 1994a, Messinian (Late Miocene) Karst on Grand Cayman, British West Indies: An Example of an Erosional Sequence Boundary: Journal of Sedimentary Research, v. B64, no 4, p. 531-541.

Jones, B., and Hunter, I.G., 1994b, Evolution of an isolated carbonate bank during Oligocene, Miocene and Pliocene times, Cayman Brac, British West Indies: Facies, v. 30, p. 25-50.

Jones, B., Hunter, I.G., and Kyser, K., 1994a, Stratigraphy of the Bluff Formation (Miocene-Pliocene) and the newly defined Brac Formation (Oligocene), Cayman Brac, B. W. I.: Caribbean Journal of Science, v. 30, no. 1-2, p. 30-51.

Jones, B., Hunter, I.G., and Kyser, K., 1994b, Revised stratigraphic nomenclature for Tertiary strata of the Cayman Islands, B.W. I.: Caribbean Journal of Science, v. 30, p. 53-68.

Jones, B. and Desrochers, A., 1992, Shallow platform carbonates, *in* Walker, R. G., and James, N.P., eds., Facies Models: Response to Sea Level Change: St. John's, Newfoundland, Geological Association of Canada, p. 277-301.

Kameo, K., Sato, T., 2000, Biogeography of Neogene calcareous nannofossils in the Caribbean and the eastern Equatorial Pacific; floral response to the emergence of the Isthmus of Panama; Marine Micropaleontology, v. 39, no. 1-4, p. 201-218.

Kemp and Frakes, 1973: Paleoclimatic significance of diachronous biogenic facies, leg 28, deep sea drilling project; Initial Reports of the Deep Sea Drilling Project, v. 28, p. 909-917.

King, T., 1996, Equatorial Pacific sea surface temperatures, faunal patterns, and carbonate burial during the Pliocene: Marine Micropaleontology, v. 27, p.63-84.

Ladd, J.W., Holcombe, T.L., Westbrook, G.K., Edgar, N.T., 1990, Caribbean marine geology; Active margins of the plate boundary, *in* G. Dengo and J. E. Case eds., The Caribbean Region (The Geology of North America; v. H), Geological Society of America, Boulder, Colorado, p. 261-290.

Larsen, A.R, 1976, Studies of recent *Amphistegina*, taxonomy and ecology: Israel Journal of Earth Science, v. 25, p. 1-26.

Li, C., 1997, Foraminifera: their distribution and utility in the interpretation of carbonate sedimentary processes around Grand Cayman, B.W.I. [unpublished Ph.D. thesis]: University of Alberta.

Liddell, D. W., and Olhurst, S.L., 1987, Patterns of reef community structure, North Jamaica: Bulletin of Marine Science, v. 40, no. 2, p. 311-329.

Machel, H.G., 2000, Dolomite formation in Caribbean Islands; driven by plate tectonics?!.:_Journal of Sedimentary Research, v. 70, no. 5, p. 977-984.

MacNeil, A. 2001, Sedimentology, Diagensis, and Dolomitization of the Pedro Castle Formation on Cayman Brac, B.W.I. [unpublished M. Sc. thesis]: University of Alberta.

Mann, P., Schubert, C., Burke, K. 1990, Review of Caribbean neotectonics, *in* G. Dengo and J. E. Case eds., The Caribbean Region (The Geology of North America; v. H), Geological Society of America, Boulder, Colorado, p. 307-338.

Marshall, P.R., 1976, Some relationships between living and total foraminiferal faunas on Pedro Bank, Jamaica: Maritime Sediments Special Publication, no. 1A, p. 61-70.

Martin and Wright, 1988, Information loss in the transition from life to death assemblages of foraminifera in back reef environments, Key Largo, Florida: Journal of Paleontology, v. 62, no. 3, p. 399-410.

Martindale, W., 1992, Calcified epibionts as palaeoecological tools: Examples from the recent in Pleistocene reefs of Barbados: Coral Reefs, v. 11, p. 167-177.

Matley, C. A., 1926, The geology of the Cayman Islands (B. W. I.) and their relation to the Bartlett Trough: The Quarterly Journal of the Geological Society of London, v. 82, p. 352-387.

Milliman,1974. Marine Carbonates, Part 1, Springer Verlag, New York.

Minnery, G. A., 1990, Crustose coralline algae from the Flower Garden Banks, northwestern Gulf of Mexico: Controls on distribution and growth morphology: Journal of Sedimentary Petrology, v. 60, no. 6, p. 992-1007.

Montpetit, J. C., 1998, Sedimentology, depositional architecture, and diagenesis of the Cayman Formation at Tarpon Springs Estates, Grand Cayman, B. W. I. [unpublished M. Sc. thesis]: University of Alberta.

Morris, A., et. al., 1990, Tectonic evolution of the Caribbean region; alternative hypothesis, *in*: Dengo G., Case J. E. eds., The Caribbean region, series The geology of North America Geological Society of America. Boulder, CO, p. 433-457.

Moussa, M.T.,Seiglie, G.A.,Meyerhoff, A.A., Taner, I., 1987 The Quebradillas Limestone (Miocen- Pliocene), northern Puerto Rico, and tectonics of the northeastern Caribbean margin; Geological Society of America Bulletin., v. 90, 427-439.

Nesbitt, H.W., Young, G.M., 1997, Sedimentation in the Venezuelan Basin, circulation in the Caribbean Sea, and onset of Northern Hemisphere glaciation: The Journal of Geology, v. 105, p. 531-544.

Ng, K., and Jones, B., 1990, Dolomitization of the Tertiary Bluff Formation on Grand Cayman, B.W.I; limitation of geochemical resolution: Geological Society of America v. 22, no.7, p. 51.

Perfit, M. R., and Heezen, B. C., 1978, The geology and evolution of the Cayman Trench: Geological Society of America Bulletin, v. 89, p. 1155-1174.

Pigram et al., 1992, Absolute magnitude of the second-order middle to late Miocene sea-level fall, Marion Plateau, northeast Australia; Geology, v.20, p. 858-862.

Pindell, J. L., and Barrett, S. F., 1990, Geological evolution of the Caribbean region; A plate-tectonic perspective, *in* G. Dengo and J. E. Case eds., The Caribbean Region (The Geology of North America; v. H), Geological Society of America, Boulder, Colorado, p. 405-432.

Pleydell, S., et al., 1990, Dolomitization of the Oligocene-Miocene Bluff Formation on Grand Cayman, British West Indies: Canadian Journal of Earth Sciences v. 27, no.3, p. 1098-1110.

Pleydell, S., and Jones, B., 1988, Boring of various faunal elements in the Oligocene-Miocene Bluff Formation of Grand Cayman, British West Indies: Journal of Paleontology, v. 62; 3, p. 348-367.

Pleydell, S.M., 1987, Aspects of diagenesis and ichnology in the Oligocene-Miocene Bluff Formation of Grand Cayman Island, British West Indies [unpublished M.Sc. thesis]: University of Alberta.

Poag, C.W., and Tresslar, R.C., 1981, Living foraminfers of West Flower Garden Bank, northernmost coral reef in the Gulf of Mexico: Micropaleontology, v. 7, p. 31-70.

Porter, J.W., 1987, Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (south Florida)—reef building corals: U.S. Fish and Wildlife Services Biol. Rep. 82(11.73) U.S. Army Corps of Engineers, TR EL-82-4. 23pp.

Reid P.R., and Macintyre, I.G., 1988, Foraminiferal-algal nodules from the Eastern Caribbean: growth history and implications on the value of nodules as paleoenvironmental indicators: Palaios v. 3, p. 424-435.

Reijmer et al., 1999, Bahamian carbonate platform development in response to paleoceanographic changes; Annual Meeting Expanded Abstracts - American Association of Petroleum Geologists. 1999; Pages A114-A115.

Rezak, R., 1977, West Flower Bank, Gulf of Mexico, *in* Frost, Weiss, and Saunders eds., Reefs and Related Carbonates- Ecology and Sedimentology, American Association of Petroleum Geologists, Tulsa, Oklahoma, p. 27-36.

Rigby, J., and Roberts, H., 1976, Geology, reefs, and marine communities of Grand Cayman Island, British West Indies: Brigham Young University Research Studies, Geology Series. Special publication no. 4, p. 1-95.

Roberts, H.H., Sneider, R. M., 1982, Reefs and associated sediments of Grand Cayman, B.W.I.: Recent Carbonate Sedimentation: Geological Society of America Field Trip Guidebook.

Rosencrantz, E., et al., 1988, Age and spreading history of the Cayman Trough as determined from depth, heat flow, and magnetic anomalies: Journal of Geophysical Research, B, Solid Earth and Planets. v. 93, no.3, p. 2141-2157.

Roth, J.M., Droxler, A. W., Kameo, K., 2000, The Caribbean carbonate crash at the middle to late Miocene transition: linkage to the establishment of the modern global

ocean conveyor, *in* Leckie, R. M., Sigurdsson, H., Acton, G. D., Draper, G., eds., Proceedings of the Ocean Drilling Program, Scientific Results, v. 165, p. 249-273.

Scoffin, T.P. 1987, An Introduction to Carbonate Sediments and Rocks, Blackie & Son Ltd.,Glascow.

Seiglie, B.A., Moussa, M.T., 1981, Late Oligocene-Pliocene transgressive-regressive cycles of sedimentation in northwestern Puerto Rico: A.A.P.G Memoir 36, p. 89-95.

Shackleton and Kennett, 1973, Late Cenozoic oxygen and carbon isotopic changes at DSDP site 284: Implications for glacial history of the Northern Hemisphere and Antartica: Initial Reports of the Deep Sea Drilling Project, v. 26, p.801-807.

Sibley, D., 1982. The origin of common dolomite fabrics: Clues from the Pliocene: Journal of Sedimentary Petrology, v. 52, no. 4, p. 1087-1100.

Sykes, L.R., McCann, W.R., Kafka, A.L., 1982, Motion of Caribbean plate during last 7 million years and implication for earlier Cenozoic movements: Journal of Geophyscial Research, v. 87 (B13), p. 10656-10676.

Triffleman, N.J., Hallock, P., Hine, A. C., 1992, Morphology, sediments, and depositional environments of a small carbonate platform: Serranilla Bank, Nicaraguan Rise, southwest Caribbean Sea: Journal of Sedimentary Petrology, v. 62, no. 4, p. 591-606.

Tucker, M.E., Wright, P. V., 1990, Carbonate Sedimentology, Blackwell Scientific Publications, London.

Vail, P.R., and Hardenbol, J., 1979, Sea-level changes during the Tertiary: Oceanus, v. 22, p.71-80.

Vénec- Peyré, M.T., 1991, Distribution of living benthic foraminifera on the back-reef and outer slopes of a high island (Moorea, French Polynesia): Coral Reefs, v. 9, p. 192-203.

Vézina, J., 1997, Stratigraphy and Sedimentology of the Pleistocene Ironshore Formation at Rogers Wreck Point, Grand Cayman: A 400 ka Record of Sea-Level Highstands [unpublished M. Sc. thesis]: University of Alberta.

Warme, J.E., 1977, Carbonate borers- their role in reef ecology and preservation, *in* Frost, Weiss, and Saunders eds., Reefs and Related Carbonates- Ecology and Sedimentology, A.A.P.G., Tulsa, Oklahoma, p. 261-280.

Wignall, B. D., 1995, Sedimentology and diagenesis of the Cayman (Miocene) and Pedro Castle (Pliocene) Formations at Safe Haven, Grand Cayman, B. W. I. [unpublished M.Sc. thesis]: University of Alberta.

Wilson, E., 1998, Depostional and Diagenetic Features of the Middle Miocene Cayman Formation, Roger's Wreck Point, Grand Cayman, B. W. I. [Unpublished M.Sc. thesis]: University of Alberta.

Wiman, S.,K., McKendree, W.G., 1975, Distribution of *Halimeda* plants and sediments on and around a patch reef near old Rhodes Key, Florida: Journal of Sedimentary Petrology, v.45, no. 2, p. 415-421.

Woodroffe, C.D. 1988, Vertical movement of isolated oceanic islands at plate margins: evidence from emergent reefs in Tonga (Pacific Ocean), Cayman Islands (Caribbean Sea) and Christmas Island (Indian Ocean): Zeitschrift für Geomorph. N. F., v. 69, p. 17-37.

Woodroffe, C. D., Stoddart D. R., Giglioli M. E., 1980, Pleistocene patch reefs and Holocene swamp morphology, Grand Cayman Island, West Indies: Journal of Biogeography, v. 7, no. 2, p. 103-113.

Woodroffe, C. D., Stoddart D. R., Harmon R. S., Spencer, T., 1983, Coastal morphology and late Quaternary history, Cayman Islands, West Indies: Quaternary Research, v. 19, no. 1, p. 64-84.

Wray, J.L., 1977, Calcareous algae (Developments in Palaeontology and Stratigraphy, 4), Elsevier Scientific Publishing Company, Amsterdam.

Wright, C.A., and Murray, J.W., 1972, Comparisons of modern and Palaeogene foraminiferal distributions and their environmental implications: Memoire Bur Rech Geo, v. 79, p. 87-96.

Appendix A

Well Logs

Core Key

Fauna

- Crustose coralline algae grains — *solitary (no flat surface) / encrusting (flat surface)
- Large coralline algae fragment
- *Halimeda*
- Bivalve
- Gastropod
- f f f — Benthic foram/ Planktic foram/ Mega- foram
- Branching *Porites*/ algal encrusted *Porites*/ rhodolith
- Branching *Stylophora*/ algal encrusted *Stylophora*/ rhodolith
- *Leptoseris*
- Massive coral
- Free-living coral
- Laminar *Porites*
- Rhodolith (noncoral nucleus)
- b — Bryozoa
- Green algae
- Echinoid

Lithologic Accessories

- o Peloid
- △ Intraclast
- M — Micrite rims/ micritization

Ichnofossils

- Boring
- Burrow

Physical Structures

- Cross Bedding

Lithology

- L/D — Proportion of limestone to dolostone

Cavity Fills

Dolomitized		Undolomitized	
Ca	Caymanite	TR	Terra Rosa
sk	Fossiliferous Grainstone		Flowstone

Post-depositional Features

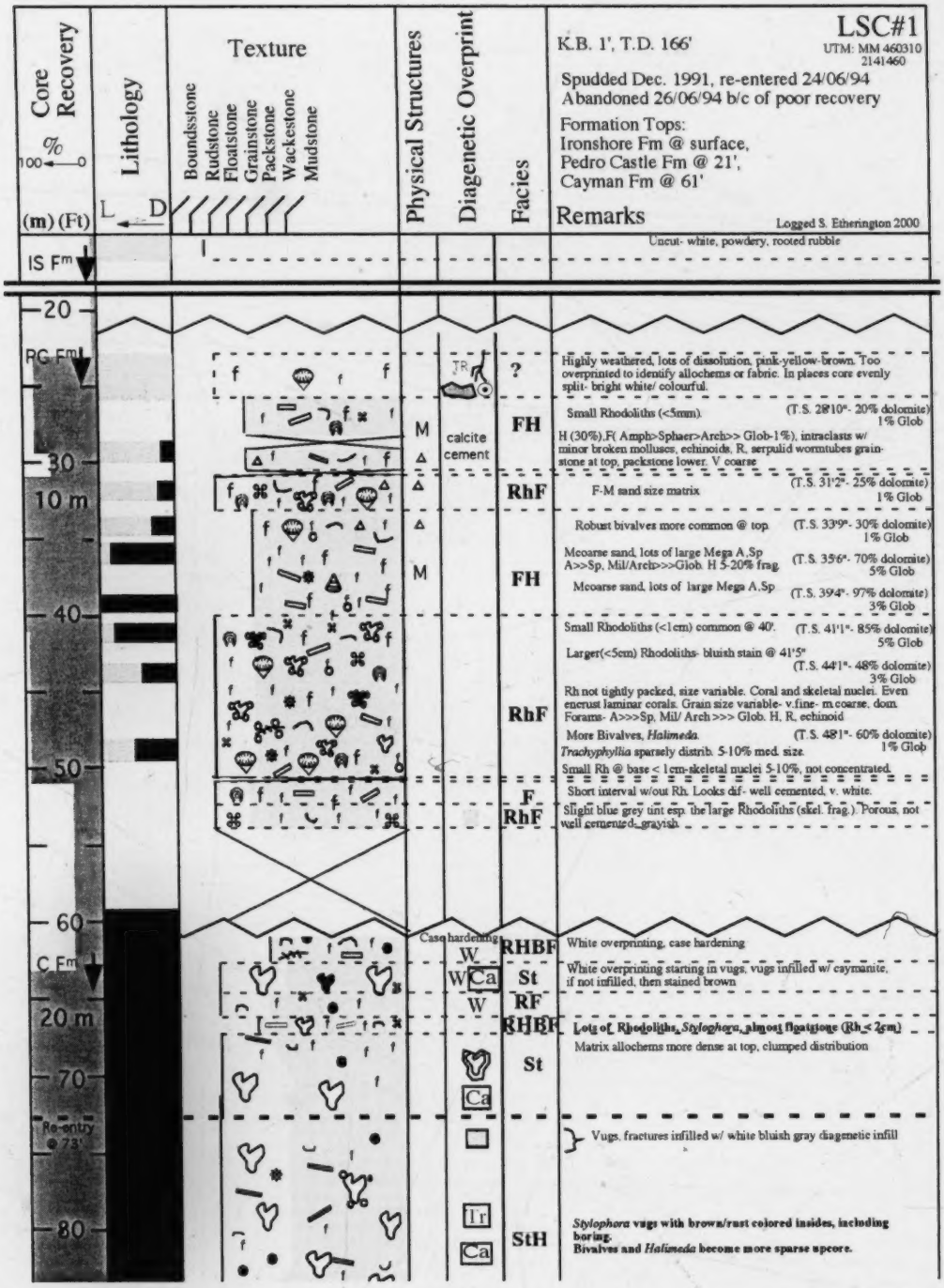
- Hard ground
- Unconformity
- Rhizoconcretions
- Terrestrial oncoids
- Bluish grey overprint
- W — Whitish overprint
- Stylophora w/ diagenetic rim
- Brownish dissolution areas
- Fracture

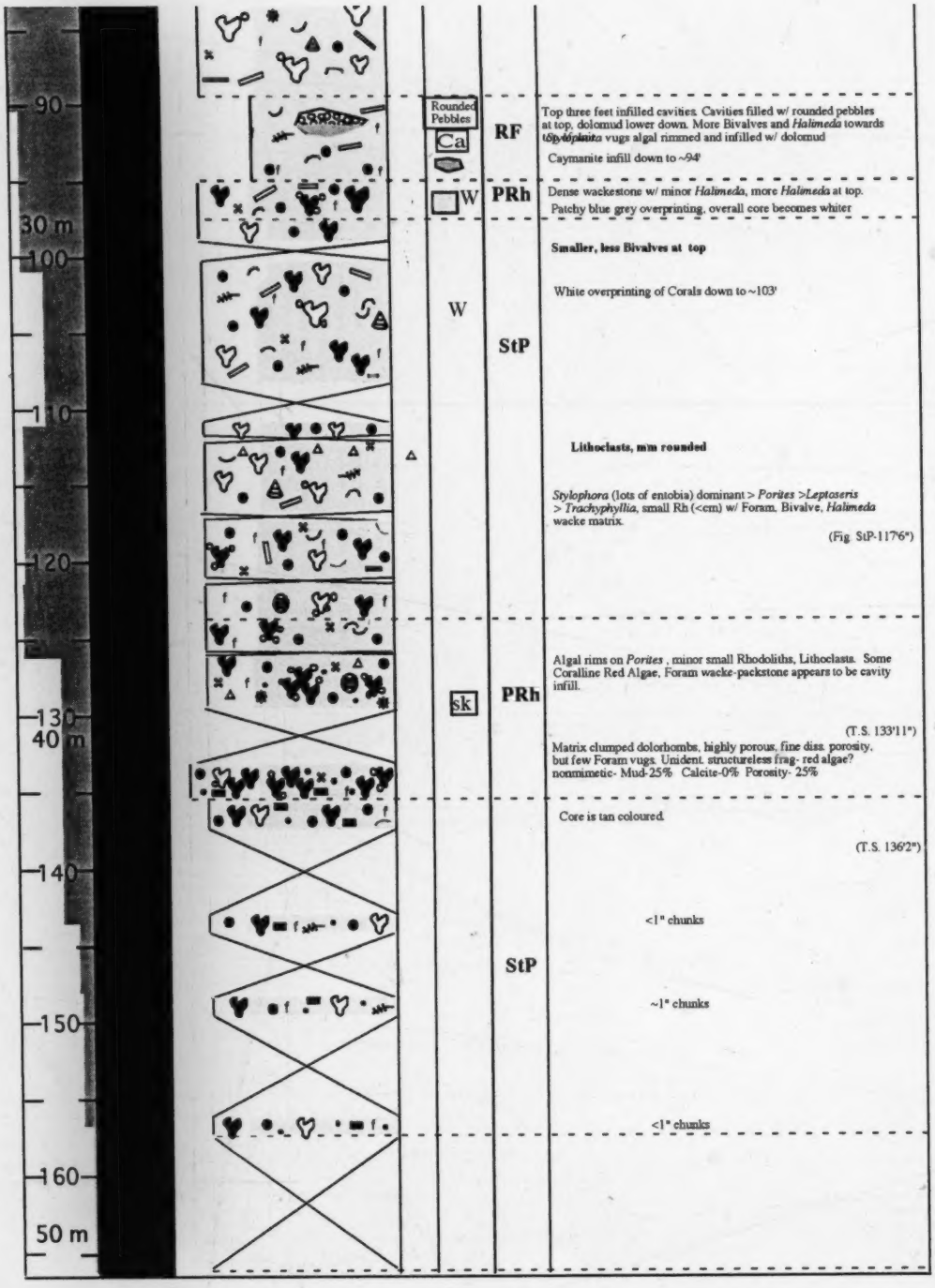
Core interval- dark fill represents matrix (<2mm), light fill represents Embry and Klovan's (1971) modified Dunham's classification based on >2mm allochems

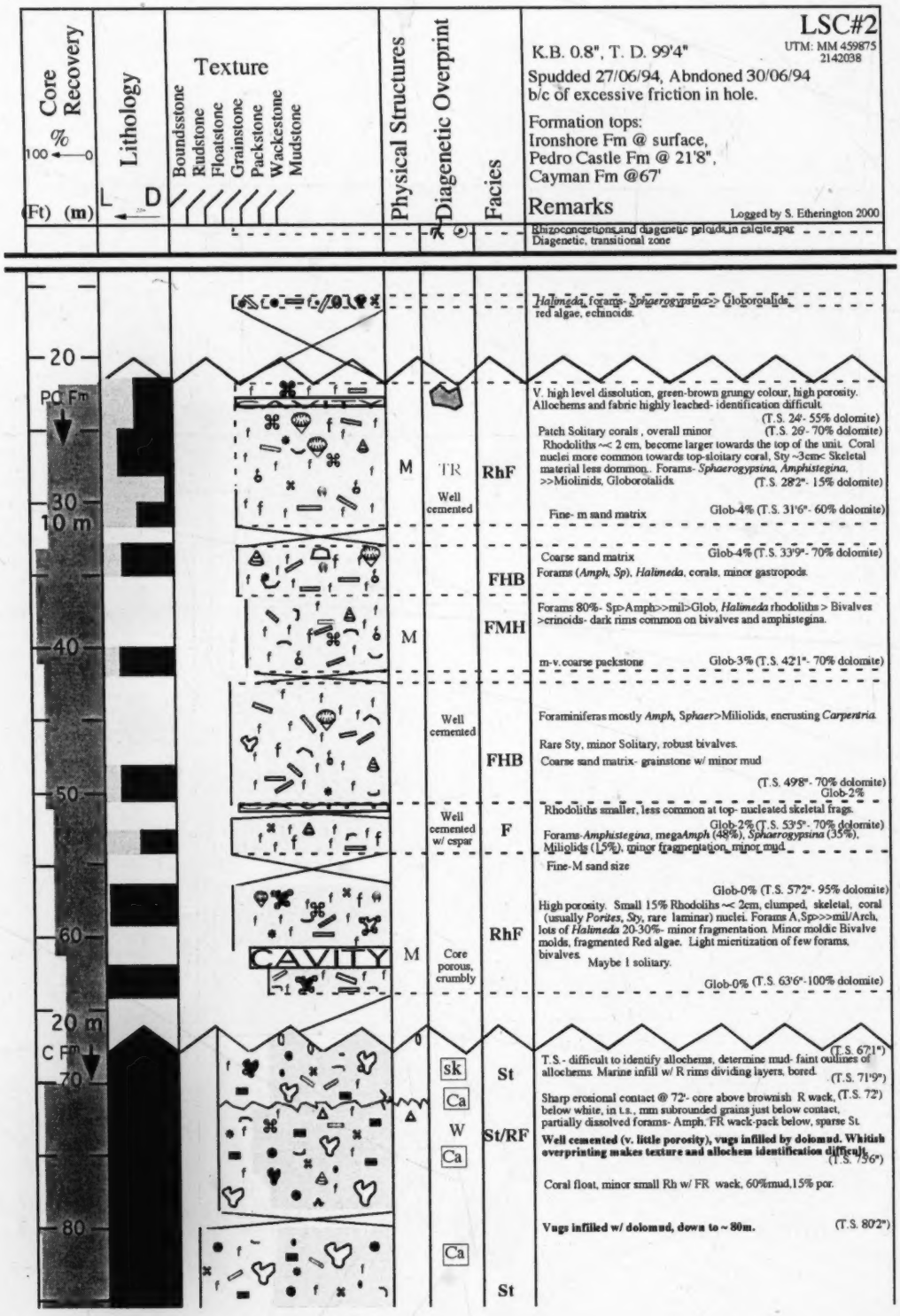
CAVITY — Cavity - as indicated by drilling report

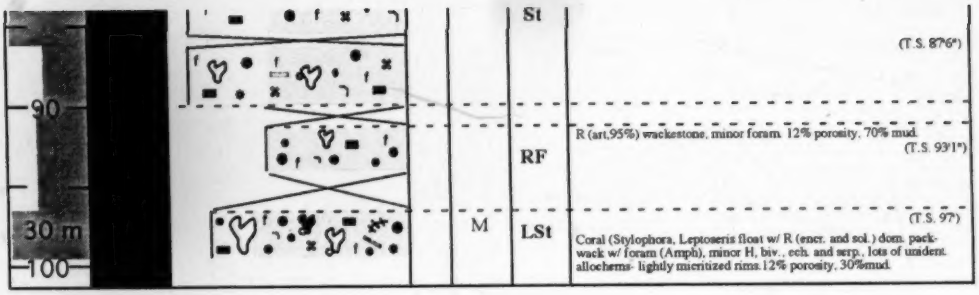
Missing Core- placed at base of core interval unless information indicates that it should be placed elsewhere.

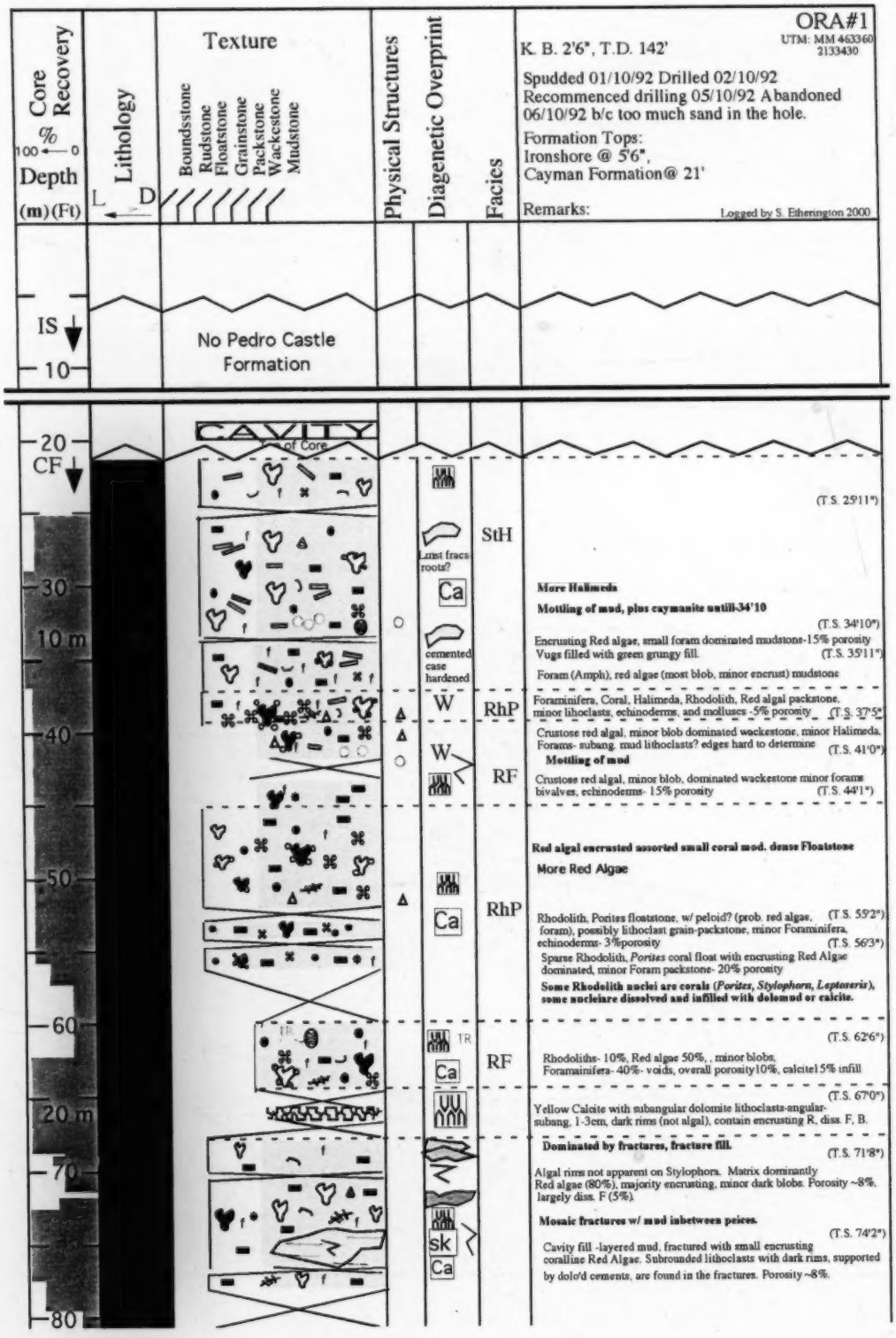
Recrystallized limestone, obliterative recrystallization
Allochem and fabric identification difficult to impossible

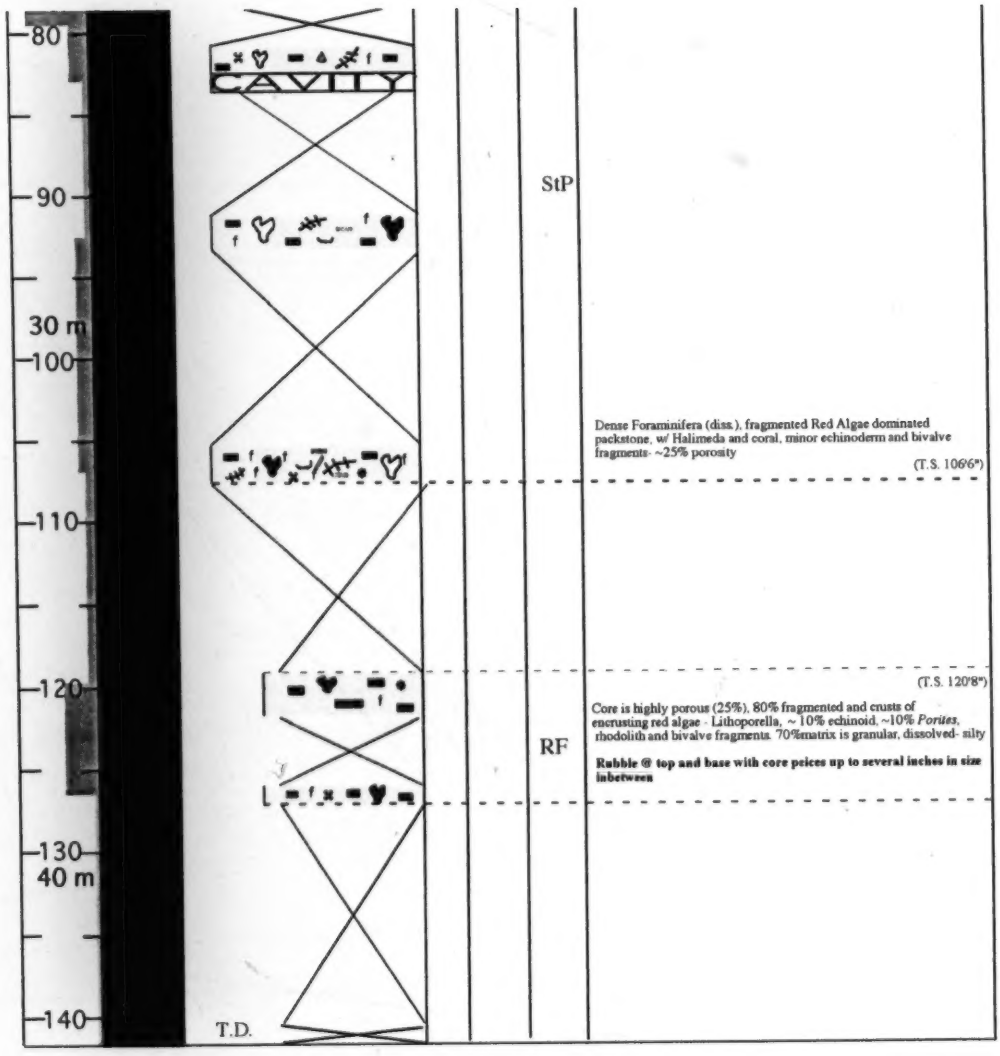

Core Recovery
%
100 ← 0
(m) (Ft)
Lithology
L D
Texture
Boundsstone
Rudstone
Floatstone
Grainstone
Packstone
Wackestone
Mudstone
Physical Structures
Diagenetic Overprint
Facies
LSC#1
K.B. 1', T.D. 166'
UTM: MM 460310
2141460
Spudded Dec. 1991, re-entered 24/06/94
Abandoned 26/06/94 b/c of poor recovery
Formation Tops:
Ironshore Fm @ surface,
Pedro Castle Fm @ 21',
Cayman Fm @ 61'
Remarks
Logged S. Etherington 2000
Uncut- white, powdery, rooted rubble
IS Fm
RC Fm
C Fm
20
30
40
50
60
70
80
10 m
20 m
Re-entry @ 73'
TR
calcite cement
Case hardening
Highly weathered, lots of dissolution, pink-yellow-brown. Too overprinted to identify allochems or fabric. In places core evenly split- bright white/ colourful.
Small Rhodoliths (<5mm). (T.S. 28'10"- 20% dolomite) 1% Glob
H (30%),F(Amph>Sphaer>Arch>> Glob-1%), intraclasts w/ minor broken molluscs, echinoids, R, serpulid wormtubes grain-stone at top, packstone lower. V coarse
F-M sand size matrix (T.S. 31'2"- 25% dolomite) 1% Glob
Robust bivalves more common @ top. (T.S. 33'9"- 30% dolomite) 1% Glob
Mcoarse sand, lots of large Mega A,Sp A>>Sp, Mil/Arch>>>Glob. H 5-20% frag. (T.S. 35'6"- 70% dolomite) 5% Glob
Mcoarse sand, lots of large Mega A,Sp (T.S. 39'4"- 97% dolomite) 3% Glob
Small Rhodoliths (<1cm) common @ 40'. (T.S. 41'1"- 85% dolomite) 5% Glob
Larger(<5cm) Rhodoliths- bluish stain @ 41'5" (T.S. 44'1"- 48% dolomite) 3% Glob
Rh not tightly packed, size variable. Coral and skeletal nuclei. Even encrust laminar corals. Grain size variable- v.fine- m.coarse, dom. Forams- A>>>Sp, Mil/ Arch >>> Glob. H, R, echinoid
More Bivalves, Halimeda. (T.S. 48'1"- 60% dolomite) 1% Glob
Trachyphyllia sparsely distrib. 5-10% med. size.
Small Rh @ base < 1cm-skeletal nuclei 5-10%, not concentrated.
Short interval w/out Rh. Looks dif- well cemented, v. white.
Slight blue grey tint esp. the large Rhodoliths (skel. frag.). Porous, not well cemented, grayish.
White overprinting, case hardening
White overprinting starting in vugs, vugs infilled w/ caymanite, if not infilled, then stained brown
Loss of Rhodoliths, Stylophora, almost flatstone (Rh < 2cm)
Matrix allochems more dense at top, clumped distribution
Vugs, fractures infilled w/ white bluish gray diagenetic infill
Stylophora vugs with brown/rust colored insides, including boring.
Bivalves and Halimeda become more sparse upcore.
FH
RhF
FH
RhF
F
RhF
RHBF
St
RF
RHBF
St
StH
M
M
W
W
W
Ca
Ca
Ir
Ca

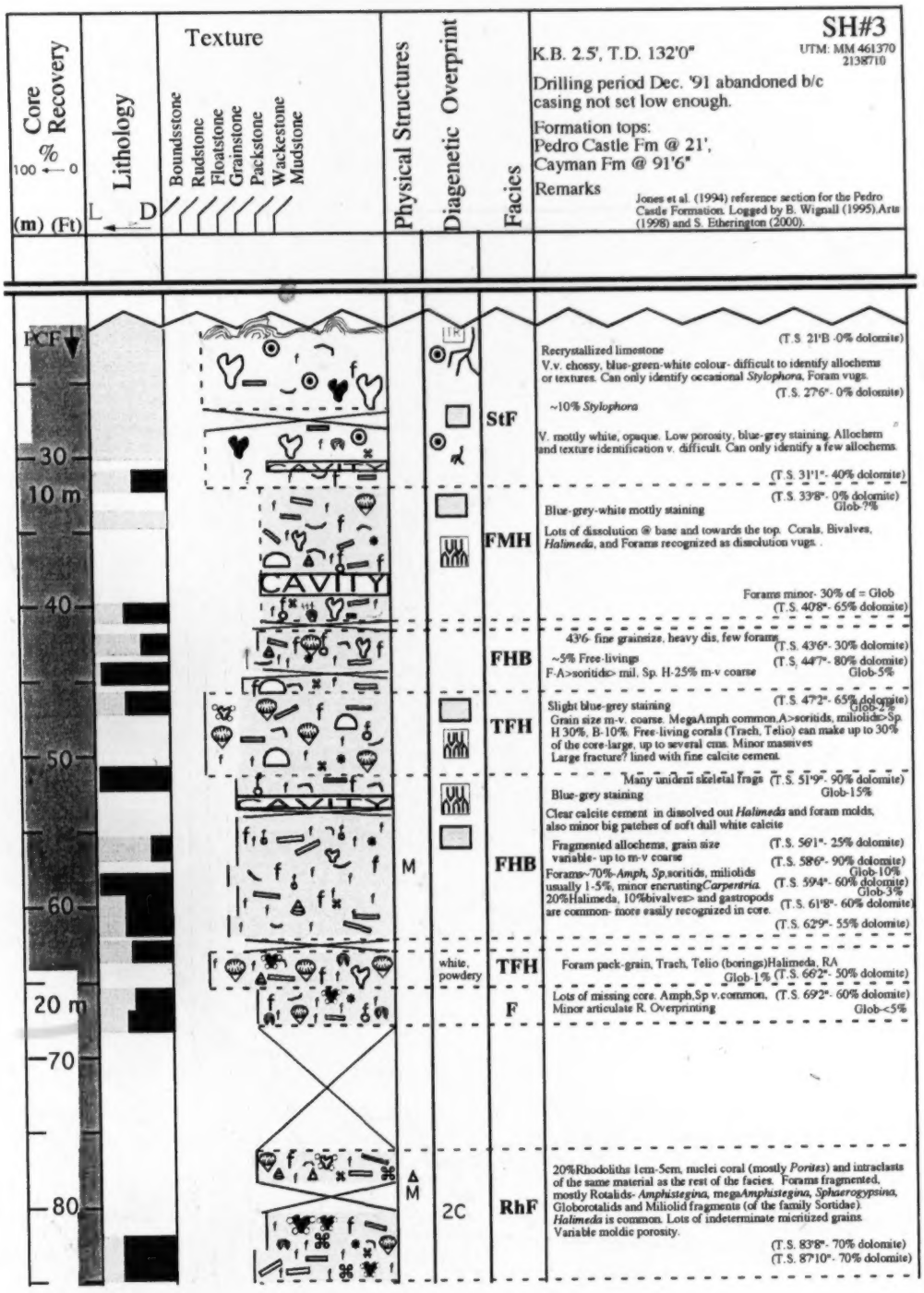

90
30 m
100
110
120
130
40 m
140
150
160
50 m
Rounded Pebbles
Ca
W
sk
RF
PRh
W
StP
PRh
StP
Top three feet infilled cavities. Cavities filled w/ rounded pebbles at top, dolomud lower down. More Bivalves and Halimeda towards top. Spelotaxita vugs algal rimmed and infilled w/ dolomud
Caymanite infill down to ~94'
Dense wackestone w/ minor Halimeda, more Halimeda at top.
Patchy blue grey overprinting, overall core becomes whiter
Smaller, less Bivalves at top
White overprinting of Corals down to ~103'
Lithoclasts, mm rounded
Stylophora (lots of entobia) dominant > Porites >Leptoseris > Trachyphyllia, small Rh (<cm) w/ Foram, Bivalve, Halimeda wacke matrix.
(Fig. StP-1176')
Algal rims on Porites , minor small Rhodoliths, Lithoclasts. Some Coralline Red Algae, Foram wacke-packstone appears to be cavity infill.
(T.S. 133'11")
Matrix clumped dolorhombs, highly porous, fine diss. porosity, but few Foram vugs. Unident. structureless frag- red algae? nonmimetic- Mud-25% Calcite-0% Porosity- 25%
Core is tan coloured.
(T.S. 136'2")
<1" chunks
~1" chunks
<1" chunks

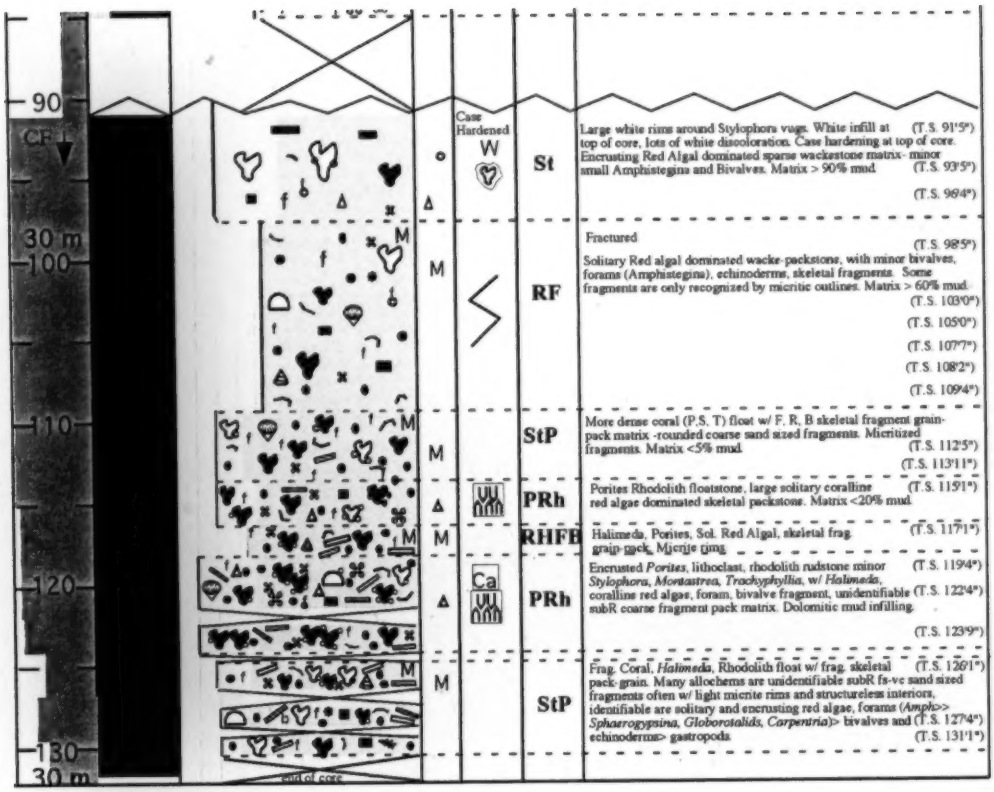

LSC#2
UTM: MM 459875 2142038
K.B. 0.8", T. D. 99'4"
Spudded 27/06/94, Abndoned 30/06/94 b/c of excessive friction in hole.
Formation tops:
Ironshore Fm @ surface,
Pedro Castle Fm @ 21'8",
Cayman Fm @67'
Remarks
Logged by S. Etherington 2000
Core Recovery %
Lithology
Texture
Boundsstone
Rudstone
Floatstone
Grainstone
Packstone
Wackestone
Mudstone
Physical Structures
Diagenetic Overprint
Facies
(Ft) (m)
Rhizoconcretions and diagenetic peloids in calcite spar
Diagenetic, transitional zone
Halimeda, forams, Sphaerogypsina>> Globorotalids, red algae, echinoids.
V. high level dissolution, green-brown grungy colour, high porosity. Allochems and fabric highly leached- identification difficult.
(T.S. 24'- 55% dolomite)
Patch Solitary corals , overall minor (T.S. 26'- 70% dolomite)
Rhodoliths =< 2 cm, become larger towards the top of the unit. Coral nuclei more common towards top-solitary coral, Sty ~3cm< Skeletal material less dommon.. Forams- Sphaerogypsina, Amphistegina, >>Miolinids, Globorotalids. (T.S. 28'2"- 15% dolomite)
Fine- m sand matrix Glob-4% (T.S. 31'6"- 60% dolomite)
Coarse sand matrix Glob-4% (T.S. 33'9"- 70% dolomite)
Forams (Amph, Sp), Halimeda, corals, minor gastropods.
Forams 80%- Sp>Amph>>mil>Glob, Halimeda rhodoliths > Bivalves >crinoids- dark rims common on bivalves and amphistegina.
m-v.coarse packstone Glob-3% (T.S. 42'1"- 70% dolomite)
Foraminiferas mostly Amph, Sphaer>Miliolids, encrusting Carpentria.
Rare Sty, minor Solitary, robust bivalves.
Coarse sand matrix- grainstone w/ minor mud
(T.S. 49'8"- 70% dolomite)
Glob-2%
Rhodoliths smaller, less common at top- nucleated skeletal frags.
Glob-2% (T.S. 53'5"- 70% dolomite)
Forams-Amphistegina, megaAmph (48%), Sphaerogypsina (35%), Miliolids (15%), minor fragmentation, minor mud.
Fine-M sand size
Glob-0% (T.S. 57'2"- 95% dolomite)
High porosity. Small 15% Rhodoliths =< 2cm, clumped, skeletal, coral (usually Porites, Sty, rare laminar) nuclei. Forams A,Sp>>mil/Arch, lots of Halimeda 20-30%- minor fragmentation. Minor moldic Bivalve molds, fragmented Red algae. Light micritization of few forams, bivalves.
Maybe 1 solitary.
Glob-0% (T.S. 63'6"- 100% dolomite)
(T.S. 67'1")
T.S.- difficult to identify allochems, determine mud- faint outlines of allochems. Marine infill w/ R rims dividing layers, bored. (T.S. 71'9")
Sharp erosional contact @ 72'- core above brownish R wack, (T.S. 72') below white, in t.s., mm subrounded grains just below contact, partially dissolved forams- Amph. FR wack-pack below, sparse St.
Well cemented (v. little porosity), vugs infilled by dolomud. Whitish overprinting makes texture and allochem identification difficult. (T.S. 75'6")
Coral float, minor small Rh w/ FR wack, 60%mud,15% por.
Vugs infilled w/ dolomud, down to ~80m. (T.S. 80'2")
PC Fm
C Fm
10 m
20 m
CAVITY
M
TR
Well cemented
Core porous, crumbly
sk
Ca
W
RhF
FHB
FMH
F
St
St/RF
20
30
40
50
60
70
80

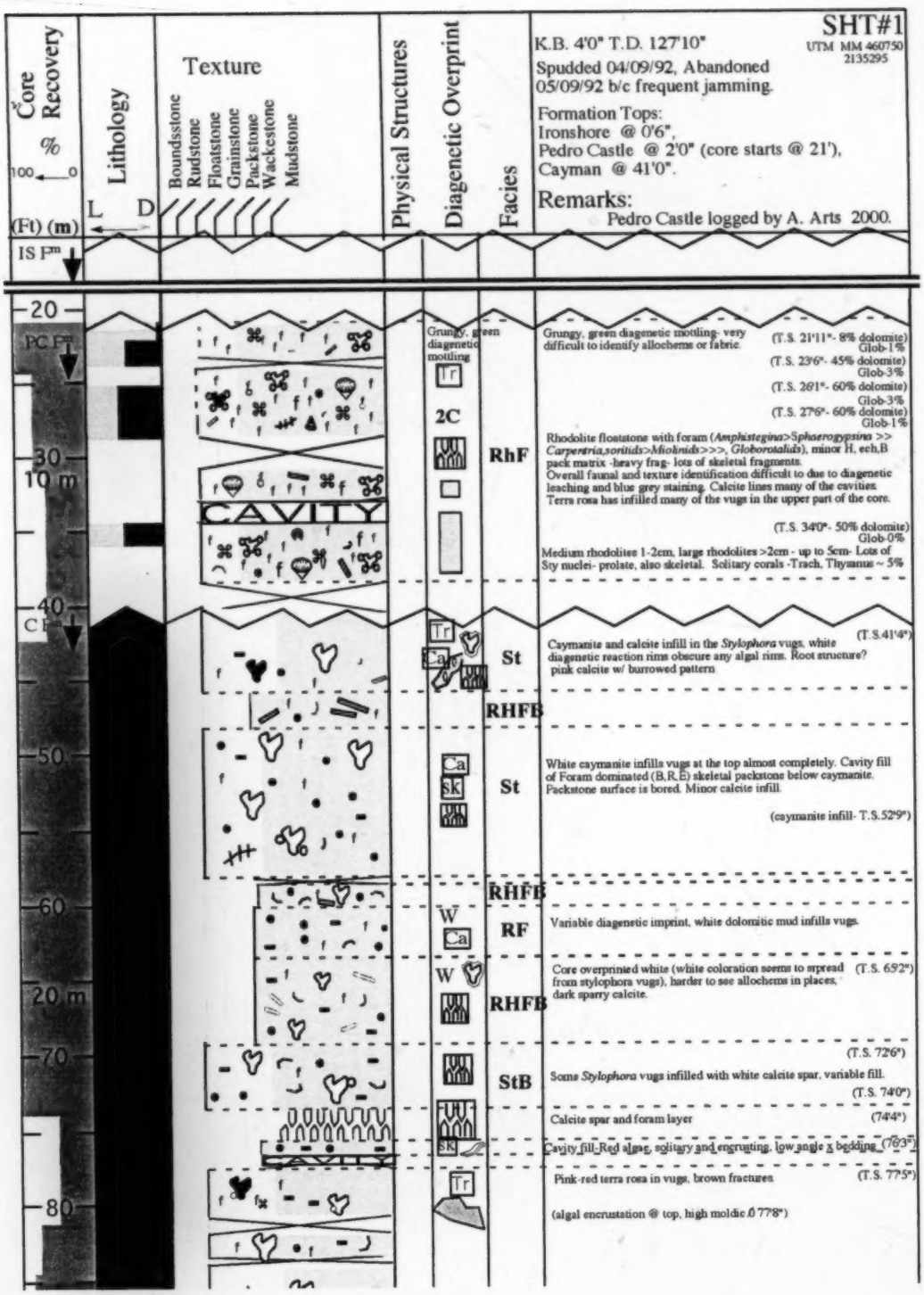

90
30 m
100
St
(T.S. 876')
RF
R (art.95%) wackestone, minor foram. 12% porosity, 70% mud.
(T.S. 931')
(T.S. 97')
M
LSt
Coral (Stylophora, Leptoseris float w/ R (encr. and sol.) dom. pack-wack w/ foram (Amph), minor H, biv., ech. and serp., lots of undent. allochems- lightly micritized rims.12% porosity, 30%mud.

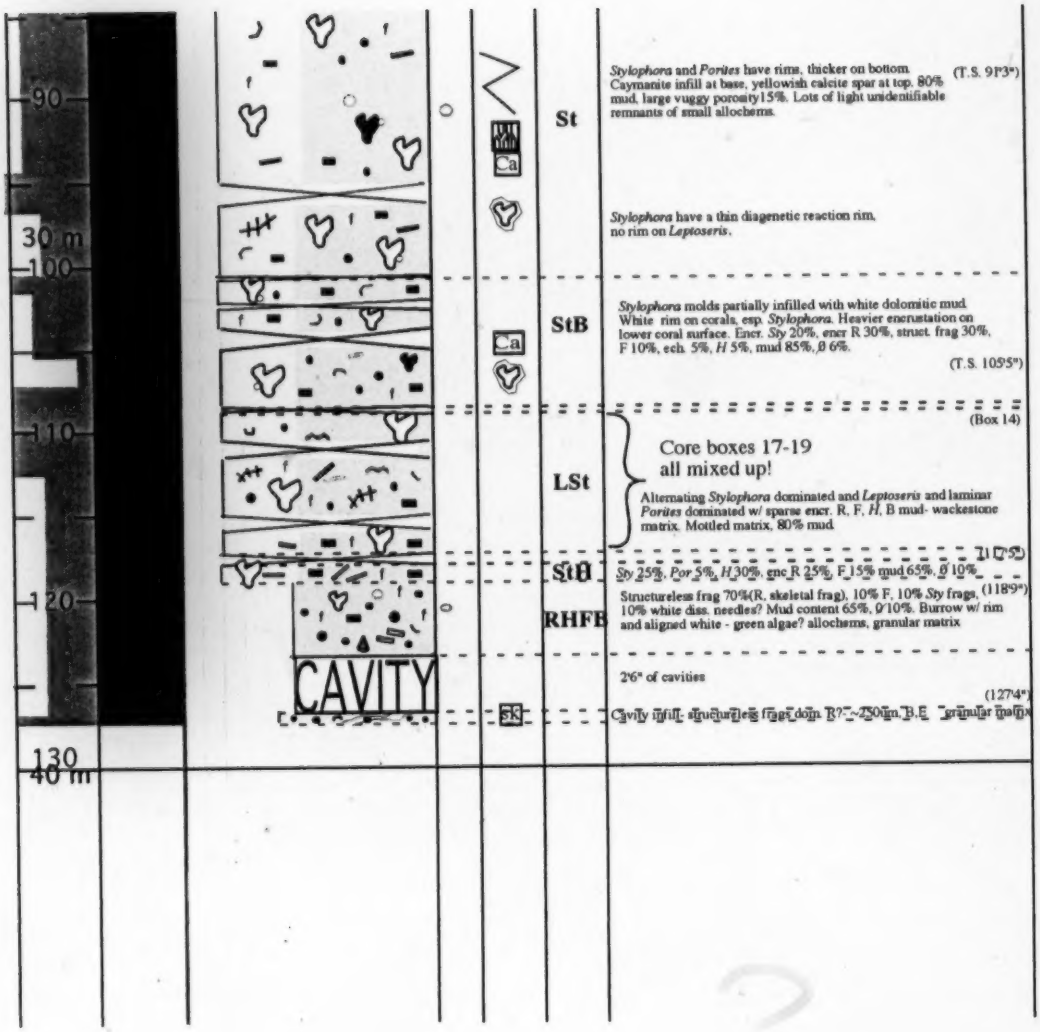

ORA#1
UTM: MM 463360 2133430
K. B. 2'6", T.D. 142'
Spudded 01/10/92 Drilled 02/10/92
Recommenced drilling 05/10/92 Abandoned
06/10/92 b/c too much sand in the hole.
Formation Tops:
Ironshore @ 5'6",
Cayman Formation@ 21'
Remarks:
Logged by S. Etherington 2000
Core Recovery %
Depth (m) (Ft)
Lithology
Texture
Boundsstone
Rudstone
Floatstone
Grainstone
Packstone
Wackestone
Mudstone
Physical Structures
Diagenetic Overprint
Facies
IS
10
No Pedro Castle Formation
20
CF
CAVITY
of Core
30
10 m
40
50
60
20 m
70
80
(T.S. 25'11")
StH
Limst fracs roots?
Ca
More Halimeda
Mottling of mud, plus caymanite until-34'10
(T.S. 34'10")
Encrusting Red algae, small foram dominated mudstone-15% porosity
Vugs filled with green grungy fill.
(T.S. 35'11")
Foram (Amph), red algae (most blob, minor encrust) mudstone
cemented case hardened
W
RhP
Foraminifera, Coral, Halimeda, Rhodolith, Red algal packstone, minor lithoclasts, echinoderms, and molluscs -5% porosity
(T.S. 37'5")
Crustose red algal, minor blob dominated wackestone, minor Halimeda, Forams- subang. mud lithoclasts? edges hard to determine
(T.S. 41'0")
Mottling of mud
RF
Crustose red algal, minor blob, dominated wackestone minor forams bivalves, echinoderms- 15% porosity
(T.S. 44'1")
Red algal encrusted assorted small coral mod. dense Floatstone
More Red Algae
Rhodolith, Porites floatstone, w/ peloid? (prob. red algae, foram), possibly lithoclast grain-packstone, minor Foraminifera, echinoderms- 3%porosity
(T.S. 55'2")
(T.S. 56'3")
Sparse Rhodolith, Porites coral float with encrusting Red Algae dominated, minor Foram packstone- 20% porosity
Some Rhodolith nuclei are corals (Porites, Stylophora, Laptoseris), some nucleiare dissolved and infilled with dolomud or calcite.
(T.S. 62'6")
TR
Rhodoliths- 10%, Red algae 50%, , minor blobs, Foramainifera- 40%- voids, overall porosity10%, calcite15% infill
(T.S. 67'0")
Yellow Calcite with subangular dolomite lithoclasts-angular-subang, 1-3cm, dark rims (not algal), contain encrusting R, diss. F, B.
Dominated by fractures, fracture fill.
(T.S. 71'8")
Algal rims not apparent on Stylophora. Matrix dominantly Red algae (80%), majority encrusting, minor dark blobs. Porosity ~8%. largely diss. F (5%).
Mosaic fractures w/ mud inbetween peices.
(T.S. 74'2")
sk
Cavity fill -layered mud, fractured with small encrusting coralline Red Algae. Subrounded lithoclasts with dark rims, supported by dolo'd cements, are found in the fractures. Porosity ~8%.

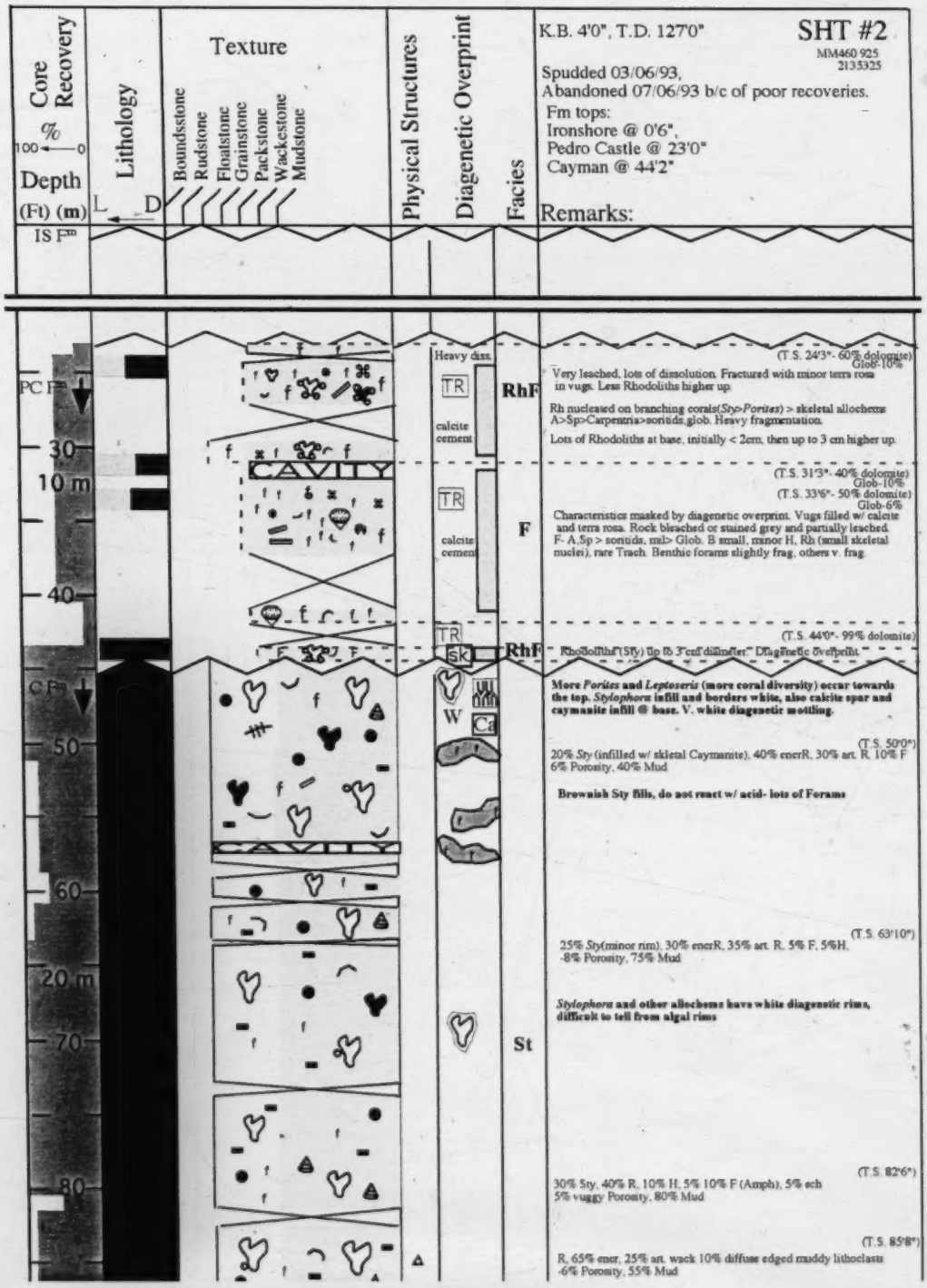

80
CAVITY
90
30 m
100
110
120
130
40 m
140
T.D.
StP
RF
Dense Foraminifera (diss.), fragmented Red Algae dominated packstone, w/ Halimeda and coral, minor echinoderm and bivalve fragments- ~25% porosity
(T.S. 106'6")
(T.S. 120'8")
Core is highly porous (25%), 80% fragmented and crusts of encrusting red algae - Lithoporella, ~ 10% echinoid, ~10% *Porites*, rhodolith and bivalve fragments. 70%matrix is granular, dissolved- silty
Rubble @ top and base with core peices up to several inches in size inbetween

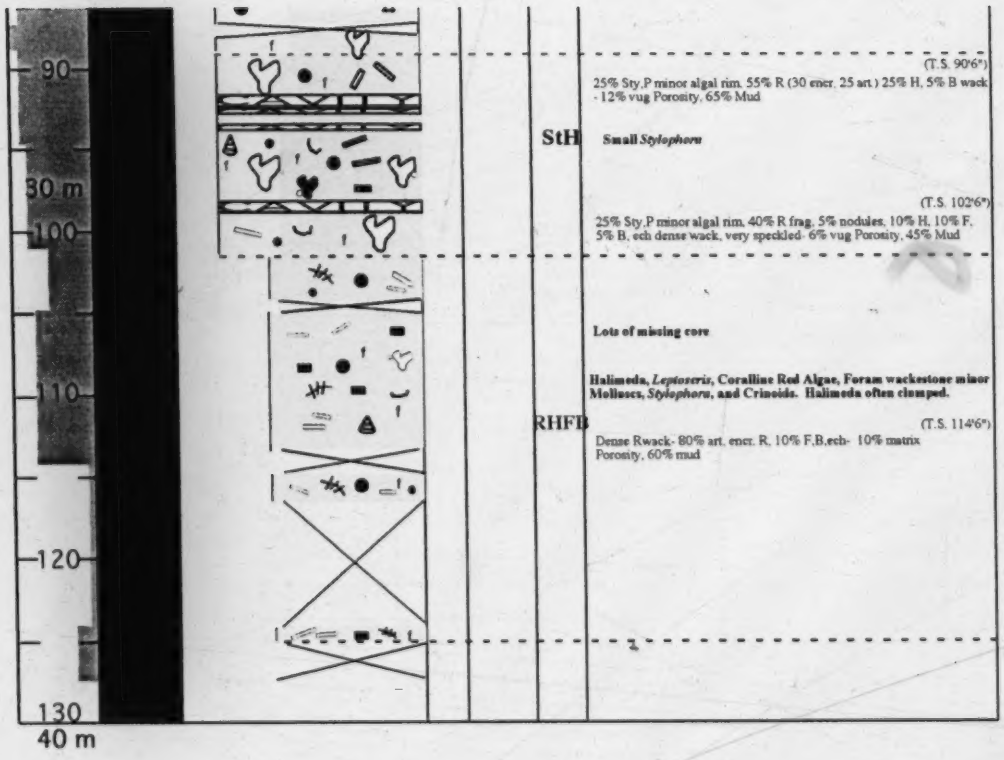

SH#3
K.B. 2.5', T.D. 132'0"
UTM: MM 461370
2138710
Drilling period Dec. '91 abandoned b/c casing not set low enough.
Formation tops:
Pedro Castle Fm @ 21',
Cayman Fm @ 91'6"
Remarks
Jones et al. (1994) reference section for the Pedro Castle Formation. Logged by B. Wignall (1995), Arts (1998) and S. Etherington (2000).
Core Recovery %
100 ← 0
(m) (Ft)
Lithology
L D
Texture
Boundsstone
Rudstone
Floatstone
Grainstone
Packstone
Wackestone
Mudstone
Physical Structures
Diagenetic Overprint
Facies
PCF
30
10 m
40
50
60
20 m
70
80
CAVITY
M
white, powdery
2C
StF
FMH
FHB
TFH
FHB
TFH
F
RhF
(T.S. 21'8 -0% dolomite)
Recrystallized limestone
V.v. chossy, blue-green-white colour - difficult to identify allochems or textures. Can only identify occasional Stylophora, Foram vugs.
(T.S. 27'6"- 0% dolomite)
~10% Stylophora
V. mottly white, opaque. Low porosity, blue-grey staining. Allochem and texture identification v. difficult. Can only identify a few allochems.
(T.S. 31'1"- 40% dolomite)
(T.S. 33'8"- 0% dolomite)
Glob-9%
Blue-grey-white mottly staining
Lots of dissolution @ base and towards the top. Corals, Bivalves, Halimeda, and Forams recognized as dissolution vugs.
Forams minor- 30% of = Glob
(T.S. 40'8"- 65% dolomite)
43'6- fine grainsize, heavy dis, few forams
(T.S. 43'6"- 30% dolomite)
~5% Free-livings
(T.S. 44'7"- 80% dolomite)
F-A>soritidc> mil, Sp. H-25% m-v coarse
Glob-5%
(T.S. 47'2"- 65% dolomite)
Glob-2%
Slight blue-grey staining
Grain size m-v. coarse. MegaAmph common,A>soritids, miliolidc>Sp H 30%, B-10%. Free-living corals (Trach, Telio) can make up to 30% of the core-large, up to several cms. Minor massives
Large fracture? lined with fine calcite cement.
Many unident skeletal frags
(T.S. 51'9"- 90% dolomite)
Glob-15%
Blue-grey staining
Clear calcite cement in dissolved out Halimeda and foram molds, also minor big patches of soft dull white calcite
Fragmented allochems, grain size variable- up to m-v coarse
(T.S. 56'1"- 25% dolomite)
(T.S. 58'6"- 90% dolomite)
Glob-10%
Forams-70%-Amph, Sp.soritids, miliolids usually 1-5%, minor encrustingCarpentria.
(T.S. 59'4"- 60% dolomite)
Glob-3%
20%Halimeda, 10%bivalves> and gastropods are common- more easily recognized in core.
(T.S. 61'8"- 60% dolomite
(T.S. 62'9"- 55% dolomite)
Foram pack-grain, Trach, Telio (borings)Halimeda, RA
Glob-1%
(T.S. 66'2"- 50% dolomite)
Lots of missing core. Amph,Sp v.common,
Minor articulate R. Overprinting
(T.S. 69'2"- 60% dolomite)
Glob-<5%
20%Rhodoliths 1cm-5cm, nuclei coral (mostly Porites) and intraclasts of the same material as the rest of the facies. Forams fragmented, mostly Rotalids- Amphistegina, megaAmphistegina, Sphaerogypsina, Globorotalids and Miliolid fragments (of the family Sortidae). Halimeda is common. Lots of indeterminate micritized grains.
Variable moldic porosity.
(T.S. 83'8"- 70% dolomite)
(T.S. 87'10"- 70% dolomite)

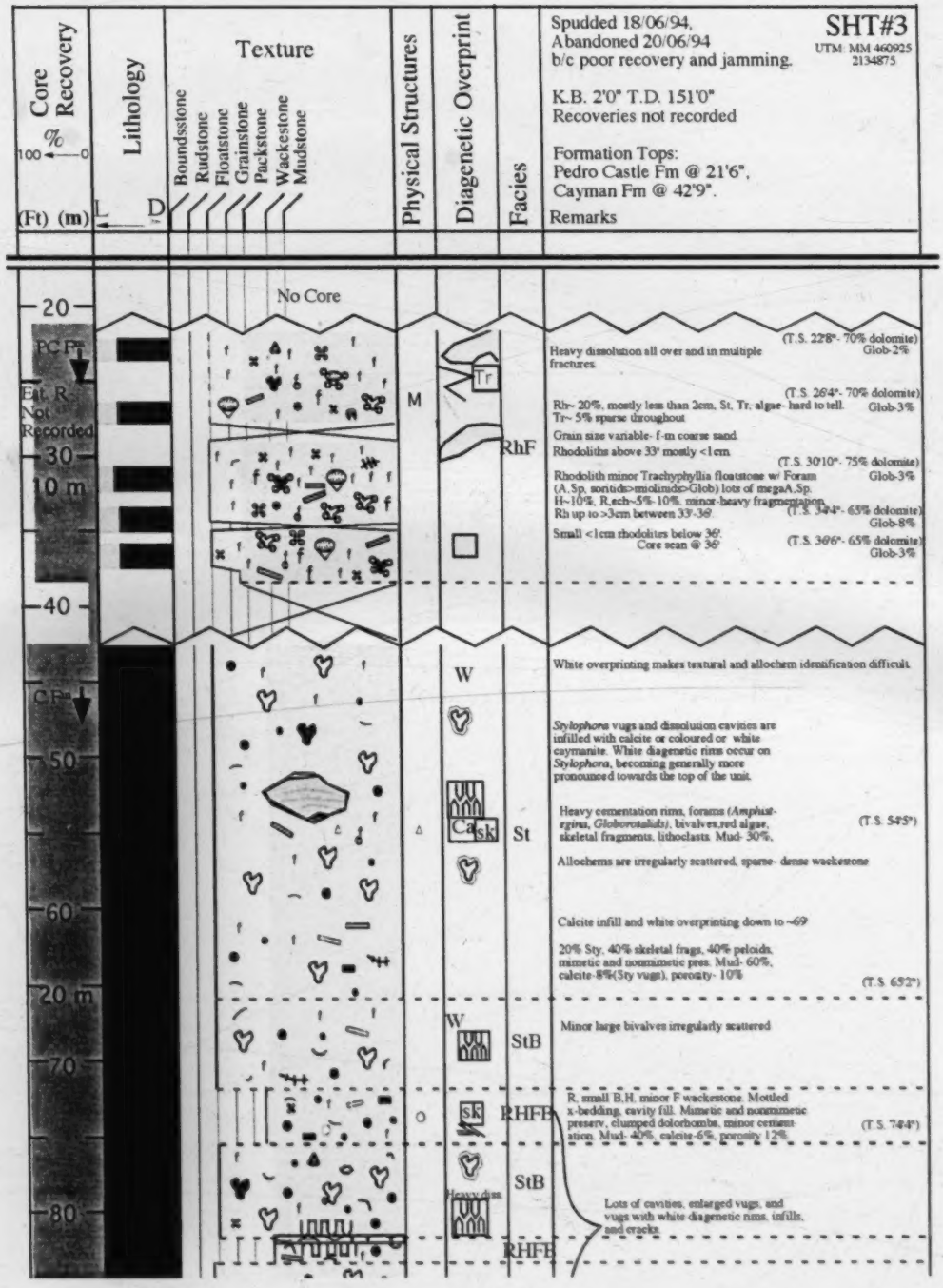

90
CF 1
30 m
100
110
120
130
30 m
end of core
Case Hardened
W
Ca
St
RF
StP
PRh
RHFB
PRh
StP
Large white rims around Stylophora vugs. White infill at top of core, lots of white discoloration. Case hardening at top of core. Encrusting Red Algal dominated sparse wackestone matrix- minor small Amphistegina and Bivalves. Matrix > 90% mud. (T.S. 91'5") (T.S. 93'5") (T.S. 98'4")
Fractured (T.S. 98'5")
Solitary Red algal dominated wacke-packstone, with minor bivalves, forams (Amphistegina), echinoderms, skeletal fragments. Some fragments are only recognized by micritic outlines. Matrix > 60% mud. (T.S. 103'0") (T.S. 105'0") (T.S. 107'7") (T.S. 108'2") (T.S. 109'4")
More dense coral (P.S. T) float w/ F, R, B skeletal fragment grain-pack matrix -rounded coarse sand sized fragments. Micritized fragments. Matrix <5% mud. (T.S. 112'5") (T.S. 113'11")
Porites Rhodolith floatstone, large solitary coralline red algae dominated skeletal packstone. Matrix <20% mud. (T.S. 115'1")
Halimeda, Porites, Sol. Red Algal, skeletal frag. grain-pack, Micrite rimg. (T.S. 117'1")
Encrusted *Porites*, lithoclast, rhodolith rudstone minor *Stylophora*, *Montastrea*, *Trachyphyllia*, w/ *Halimeda*, corallina red algae, foram, bivalve fragment, unidentifiable subR coarse fragment pack matrix. Dolomitic mud infilling. (T.S. 119'4") (T.S. 122'4") (T.S. 123'9")
Frag. Coral, *Halimeda*, Rhodolith float w/ frag. skeletal pack-grain. Many allochems are unidentifiable subR fs-vc sand sized fragments often w/ light micrite rims and structureless interiors, identifiable are solitary and encrusting red algae, forams (*Amph*>> *Sphaerogypsina*, *Globorotalids*, *Carpentria*)> bivalves and (T.S. 127'4") echinoderms> gastropods. (T.S. 126'1") (T.S. 131'1")

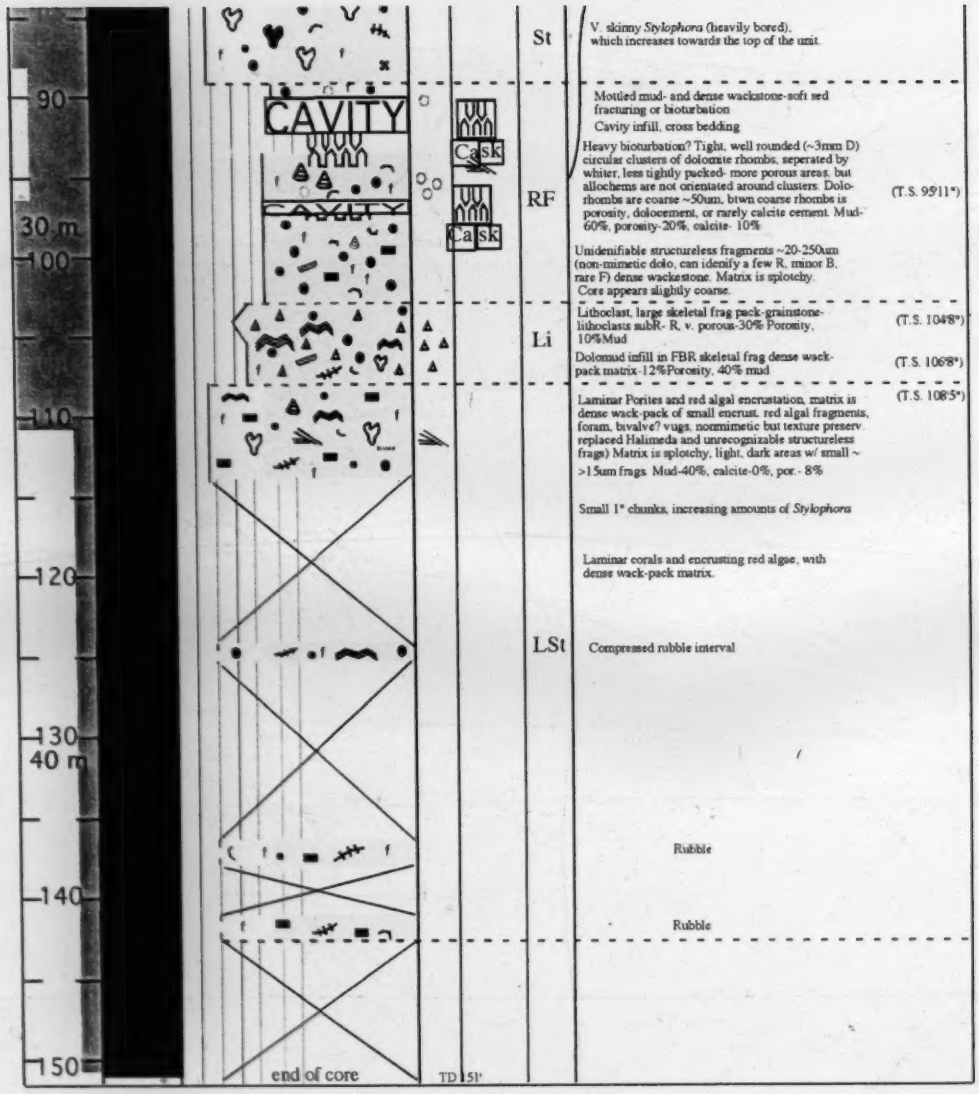

SHT#1
UTM MM 460750 2135295
K.B. 4'0" T.D. 127'10"
Spudded 04/09/92, Abandoned 05/09/92 b/c frequent jamming.
Formation Tops:
Ironshore @ 0'6",
Pedro Castle @ 2'0" (core starts @ 21'),
Cayman @ 41'0".
Remarks:
Pedro Castle logged by A. Arts 2000.
Core Recovery %
100 0
(Ft) (m)
Lithology
L D
Texture
Boundsstone
Rudstone
Floatstone
Grainstone
Packstone
Wackestone
Mudstone
Physical Structures
Diagenetic Overprint
Facies
IS Fm
PC Fm
C Fm
20
30
10 m
40
50
60
20 m
70
80
CAVITY
CAVITY
Grungy, green diagenetic mottling
Tr
2C
RhF
Grungy, green diagenetic mottling- very difficult to identify allochems or fabric. (T.S. 21'11"- 8% dolomite) Glob-1%
(T.S. 23'6"- 45% dolomite) Glob-3%
(T.S. 26'1"- 60% dolomite) Glob-3%
(T.S. 27'6"- 60% dolomite) Glob-1%
Rhodolite floatstone with foram (Amphistegina>Sphaerogypsina >> Carpentria,soritids>Miolnids>>>, Globorotalids), minor H, ech,B pack matrix -heavy frag- lots of skeletal fragments.
Overall faunal and texture identification difficult to due to diagenetic leaching and blue grey staining. Calcite lines many of the cavities.
Terra rosa has infilled many of the vugs in the upper part of the core.
(T.S. 34'0"- 50% dolomite) Glob-0%
Medium rhodolites 1-2cm, large rhodolites >2cm - up to 5cm- Lots of Sty nuclei- prolate, also skeletal. Solitary corals -Trach, Thysanus ~ 5%
Tr
Ca
St
(T.S.41'4")
Caymanite and calcite infill in the Stylophora vugs, white diagenetic reaction rims obscure any algal rims. Root structure? pink calcite w/ burrowed pattern
RHFB
Ca
sk
St
White caymanite infills vugs at the top almost completely. Cavity fill of Foram dominated (B,R,E) skeletal packstone below caymanite. Packstone surface is bored. Minor calcite infill.
(caymanite infill- T.S.52'9")
RHFB
W
Ca
RF
Variable diagenetic imprint, white dolomitic mud infills vugs.
W
RHFB
Core overprinted white (white coloration seems to spread from stylophora vugs), harder to see allochems in places, dark sparry calcite.
(T.S. 65'2")
(T.S. 72'6")
StB
Some Stylophora vugs infilled with white calcite spar, variable fill.
(T.S. 74'0")
Calcite spar and foram layer
(74'4")
sk
Cavity fill-Red algae, solitary and encrusting, low angle x bedding (76'3")
Tr
Pink-red terra rosa in vugs, brown fractures
(T.S. 77'5")
(algal encrustation @ top, high moldic @ 77'8")


90
30 m
100
110
120
130
40 m
CAVITY
Ca
Ca
sk
St
StB
LSt
StB
RHFB
Stylophora and *Porites* have rims, thicker on bottom. Caymanite infill at base, yellowish calcite spar at top. 80% mud, large vuggy porosity15%. Lots of light unidentifiable remnants of small allochems. (T.S. 91'3")
Stylophora have a thin diagenetic reaction rim, no rim on *Leptoseris*.
Stylophora molds partially infilled with white dolomitic mud. White rim on corals, esp. *Stylophora*. Heavier encrustation on lower coral surface. Encr. *Sty* 20%, encr R 30%, struct. frag 30%, F 10%, ech. 5%, *H* 5%, mud 85%, Ø 6%. (T.S. 105'5")
(Box 14)
Core boxes 17-19 all mixed up!
Alternating *Stylophora* dominated and *Leptoseris* and laminar *Porites* dominated w/ sparse encr. R, F, *H*, B mud- wackestone matrix. Mottled matrix, 80% mud.
Sty 25%, *Por* 5%, *H* 30%, encr R 25%, F 15% mud 65%, Ø 10%
Structureless frag 70%(R, skeletal frag), 10% F, 10% *Sty* frags, 10% white diss. needles? Mud content 65%, Ø 10%. Burrow w/ rim and aligned white - green algae? allochems, granular matrix (118'9")
2'6" of cavities (127'4")
Cavity infill- structureless frag. dom. R?, ~50% m.B.E. granular matrix


Core Recovery
%
100 ← 0
Depth
(Ft) (m)
Lithology
L D
Texture
Boundsstone
Rudstone
Floatstone
Grainstone
Packstone
Wackestone
Mudstone
Physical Structures
Diagenetic Overprint
Facies
K.B. 4'0", T.D. 127'0"
SHT #2
MM460 925
2135325
Spudded 03/06/93,
Abandoned 07/06/93 b/c of poor recoveries.
Fm tops:
Ironshore @ 0'6",
Pedro Castle @ 23'0"
Cayman @ 44'2"
Remarks:
IS Fm
PC Fm
CF Fm
30
10 m
40
50
60
20 m
70
80
CAVITY
CAVITY
Heavy diss.
TR
calcite cement
RhF
TR
calcite cement
F
TR
sk
RhF
W
Ca
St
(T.S. 24'3"- 60% dolomite)
Glob-10%
Very leached, lots of dissolution. Fractured with minor terra rosa in vugs. Less Rhodoliths higher up.
Rh nucleated on branching corals(Sty>Porites) > skeletal allochems A>Sp>Carpentria>soritids,glob. Heavy fragmentation.
Lots of Rhodoliths at base, initially < 2cm, then up to 3 cm higher up.
(T.S. 31'3"- 40% dolomite)
Glob-10%
(T.S. 33'6"- 50% dolomite)
Glob-6%
Characteristics masked by diagenetic overprint. Vugs filled w/ calcite and terra rosa. Rock bleached or stained grey and partially leached. F- A,Sp > soritids, mil> Glob. B small, minor H, Rh (small skeletal nuclei), rare Trach. Benthic forams slightly frag, others v. frag.
(T.S. 44'0"- 99% dolomite)
Rhodolithsf (Sty) up to 3 cm diameter. Diagenetic overprint.
More Porites and Leptoseris (more coral diversity) occur towards the top. Stylophora infill and borders white, also calcite spar and caymanite infill @ base. V. white diagenetic mottling.
(T.S. 50'0")
20% Sty (infilled w/ skletal Caymanite), 40% encrR, 30% art. R, 10% F
6% Porosity, 40% Mud
Brownish Sty fills, do not react w/ acid- lots of Forams
(T.S. 63'10")
25% Sty(minor rim), 30% encrR, 35% art. R, 5% F, 5%H,
-8% Porosity, 75% Mud
Stylophora and other allochems have white diagenetic rims, difficult to tell from algal rims
(T.S. 82'6")
30% Sty, 40% R, 10% H, 5% 10% F (Amph), 5% ech
5% vuggy Porosity, 80% Mud
(T.S. 85'8")
R, 65% encr, 25% art. wack 10% diffuse edged muddy lithoclasts
-6% Porosity, 55% Mud


90
30 m
100
110
120
130
40 m
StH
RHFB
(T.S. 90'6")
25% Sty.P minor algal rim. 55% R (30 encr. 25 art.) 25% H, 5% B wack - 12% vug Porosity, 65% Mud
Small Stylophora
(T.S. 102'6")
25% Sty.P minor algal rim. 40% R frag. 5% nodules. 10% H, 10% F, 5% B, ech dense wack, very speckled- 6% vug Porosity, 45% Mud
Lots of missing core
Halimeda, Leptoseris, Coralline Red Algae, Foram wackestone minor Molluscs, Stylophora, and Crinoids. Halimeda often clumped.
(T.S. 114'6")
Dense Rwack- 80% art. encr. R, 10% F,B,ech- 10% matrix
Porosity, 60% mud


Core Recovery
%
100 ← → 0
(Ft) (m)
Lithology
L
D
Texture
Boundstone
Rudstone
Floatstone
Grainstone
Packstone
Wackestone
Mudstone
Physical Structures
Diagenetic Overprint
Facies
Spudded 18/06/94,
Abandoned 20/06/94
b/c poor recovery and jamming.
SHT#3
UTM: MM 460925
2134875
K.B. 2'0" T.D. 151'0"
Recoveries not recorded
Formation Tops:
Pedro Castle Fm @ 21'6",
Cayman Fm @ 42'9".
Remarks
No Core
20
30
40
50
60
70
80
10 m
20 m
PC Fm
CR Fm
Est. R
Not
Recorded
M
W
Tr
RhF
Cask
St
StB
RHFB
sk
Heavy diss.
Heavy dissolution all over and in multiple fractures.
(T.S. 22'8"- 70% dolomite) Glob-2%
(T.S. 26'4"- 70% dolomite)
Rh~ 20%, mostly less than 2cm, St, Tr: algae- hard to tell. Glob-3%
Tr~ 5% sparse throughout
Grain size variable- f-m coarse sand.
Rhodoliths above 33' mostly <1cm
(T.S. 30'10"- 75% dolomite)
Rhodolith minor Trachyphyllia floatstone w/ Foram Glob-3%
(A.Sp, sontids>miolinids>Glob) lots of megaA.Sp.
H~10%, R,ech~5%-10%, minor-heavy fragmentation
Rh up to >3cm between 33'-36'
(T.S. 34'4"- 65% dolomite)
Glob-8%
Small <1cm rhodolites below 36'.
Core scan @ 36'
(T.S. 36'6"- 65% dolomite)
Glob-3%
White overprinting makes textural and allochem identification difficult.
Stylophora vugs and dissolution cavities are infilled with calcite or coloured or white caymanite. White diagenetic rims occur on Stylophora, becoming generally more pronounced towards the top of the unit.
Heavy cementation rims, forams (Amphistegina, Globorotalids), bivalves,red algae, skeletal fragments, lithoclasts. Mud- 30%,
(T.S. 54'5")
Allochems are irregularly scattered, sparse- dense wackestone
Calcite infill and white overprinting down to ~69'
20% Sty, 40% skeletal frags, 40% peloids, mimetic and nonmimetic pres. Mud- 60%, calcite-8%(Sty vugs), porosity- 10%
(T.S. 65'2")
Minor large bivalves irregularly scattered
R, small B.H, minor F wackestone. Mottled x-bedding, cavity fill. Mimetic and nonmimetic preserv, clumped dolorhombs, minor cementation. Mud- 40%, calcite-6%, porosity 12%.
(T.S. 74'4")
Lots of cavities, enlarged vugs, and vugs with white diagenetic rims, infills, and cracks.


90
30 m
100
110
120
130
40 m
140
150
CAVITY
CAVITY
Cask
Cask
St
RF
Li
LSt
V. skinny Stylophora (heavily bored), which increases towards the top of the unit.
Mottled mud- and dense wackstone-soft sed fracturing or bioturbation
Cavity infill, cross bedding
Heavy bioturbation? Tight, well rounded (~3mm D) circular clusters of dolomite rhombs, seperated by whiter, less tightly packed- more porous areas, but allochems are not orientated around clusters. Dolo-rhombs are coarse ~50um, btwn coarse rhombs is porosity, dolocement, or rarely calcite cement. Mud-60%, porosity-20%, calcite- 10%
(T.S. 9911*)
Unidenifiable structureless fragments ~20-250um (non-mimetic dolo, can idenify a few R, minor B, rare F) dense wackestone. Matrix is splotchy. Core appears slightly coarse.
Lithoclast, large skeletal frag pack-grainstone-lithoclasts subR- R, v. porous-30% Porosity, 10%Mud
(T.S. 1048*)
Dolomud infill in FBR skeletal frag dense wack-pack matrix-12%Porosity, 40% mud
(T.S. 1069*)
Laminar Porites and red algal encrustation, matrix is dense wack-pack of small encrust. red algal fragments, foram, bivalve? vugs, nonmimetic but texture preserv. replaced Halimeda and unrecognizable structureless frags) Matrix is splotchy, light, dark areas w/ small ~ >15um frags. Mud-40%, calcite-0%, por.- 8%
(T.S. 1085*)
Small 1" chunks, increasing amounts of Stylophora
Laminar corals and encrusting red algae, with dense wack-pack matrix.
Compressed rubble interval
Rubble
Rubble
end of core
TD 151'